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(54) **MASS SPECTROMETER HAVING AN ION GUIDE WITH AN AXIAL FIELD**

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H01J 49/06 (2006.01)

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USPC **250/292**; 250/283

(58) **Field of Classification Search**
CPC H01J 49/063
USPC 250/283
See application file for complete search history.

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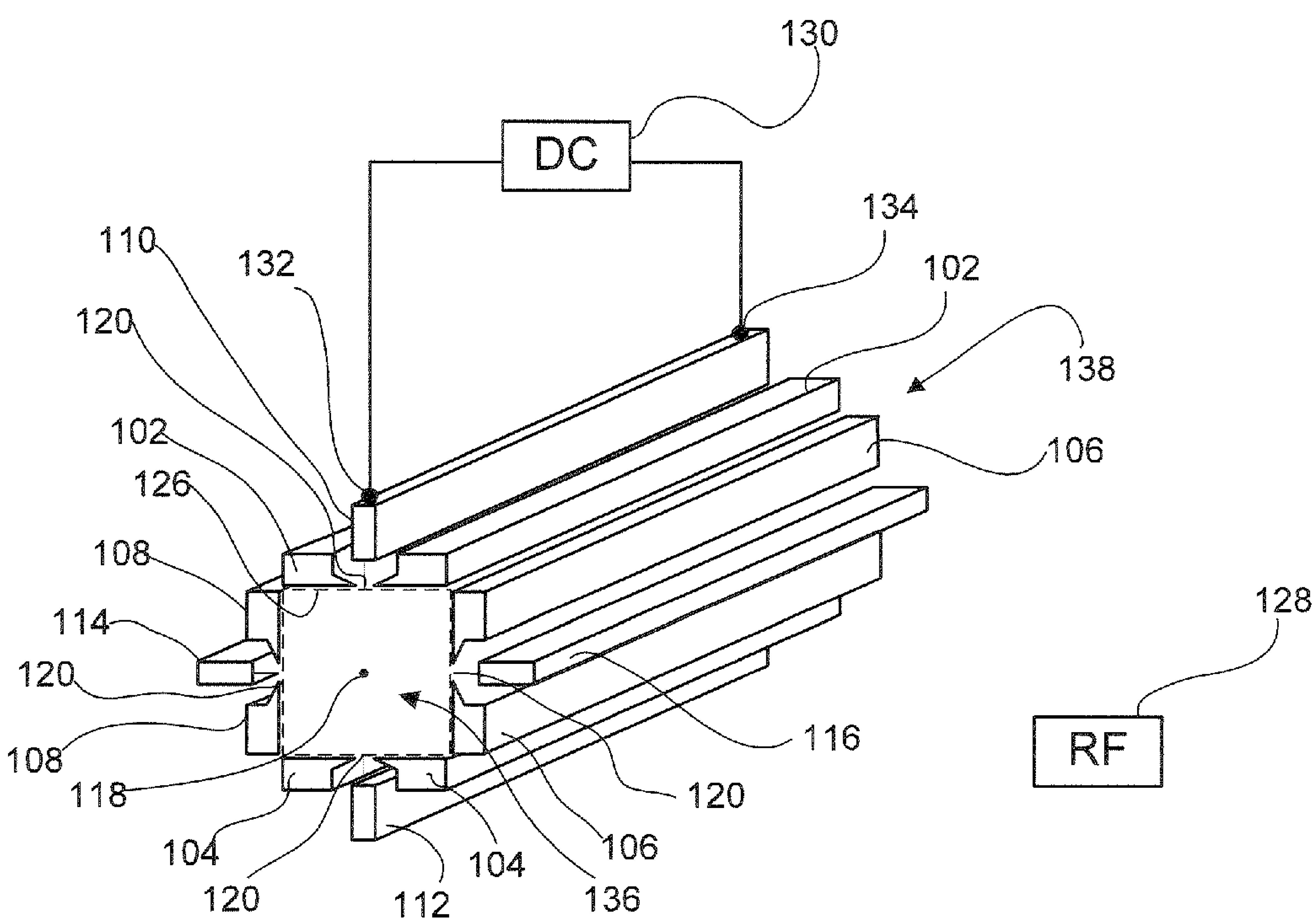
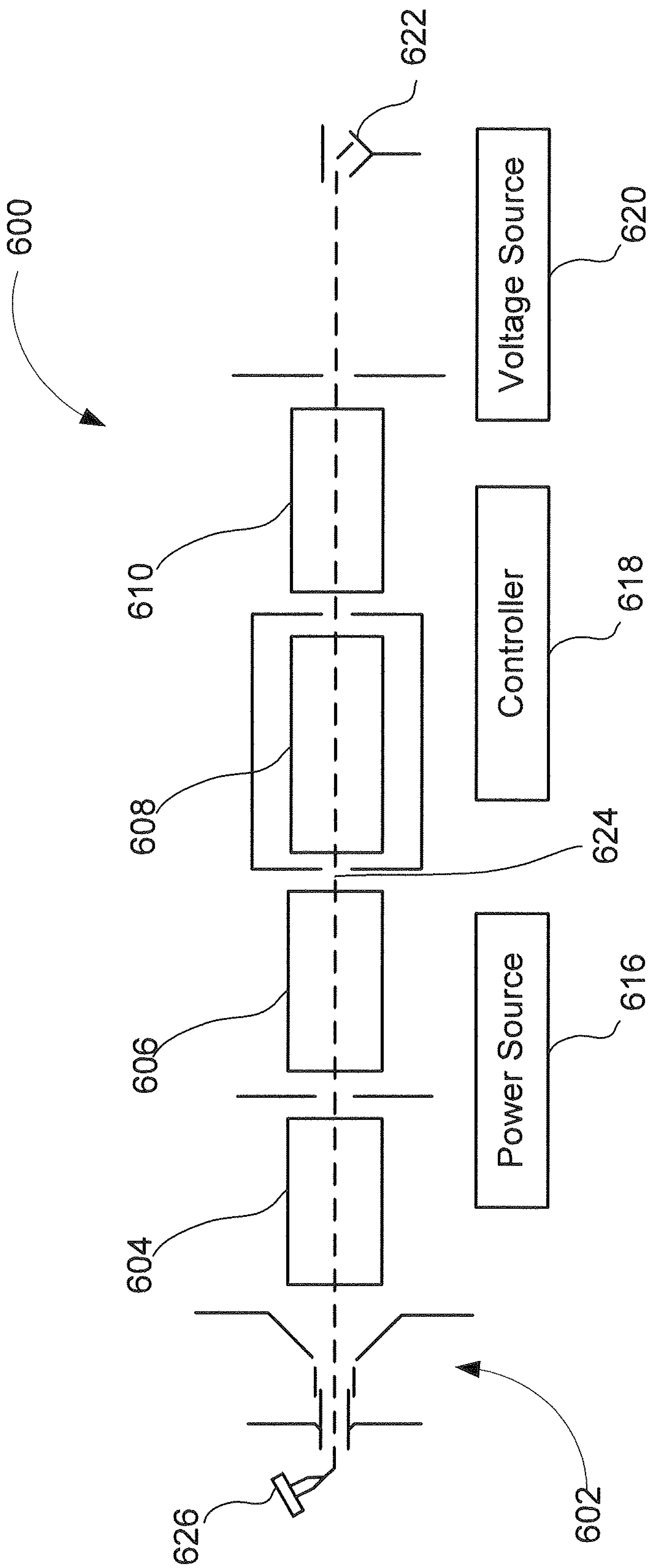
(57) **ABSTRACT**

A mass spectrometer having an ion guide with an axial field is described. The ion guide includes electrodes with longitudinally extending gaps and inserts configured to be proximate to the gaps.

24 Claims, 15 Drawing Sheets

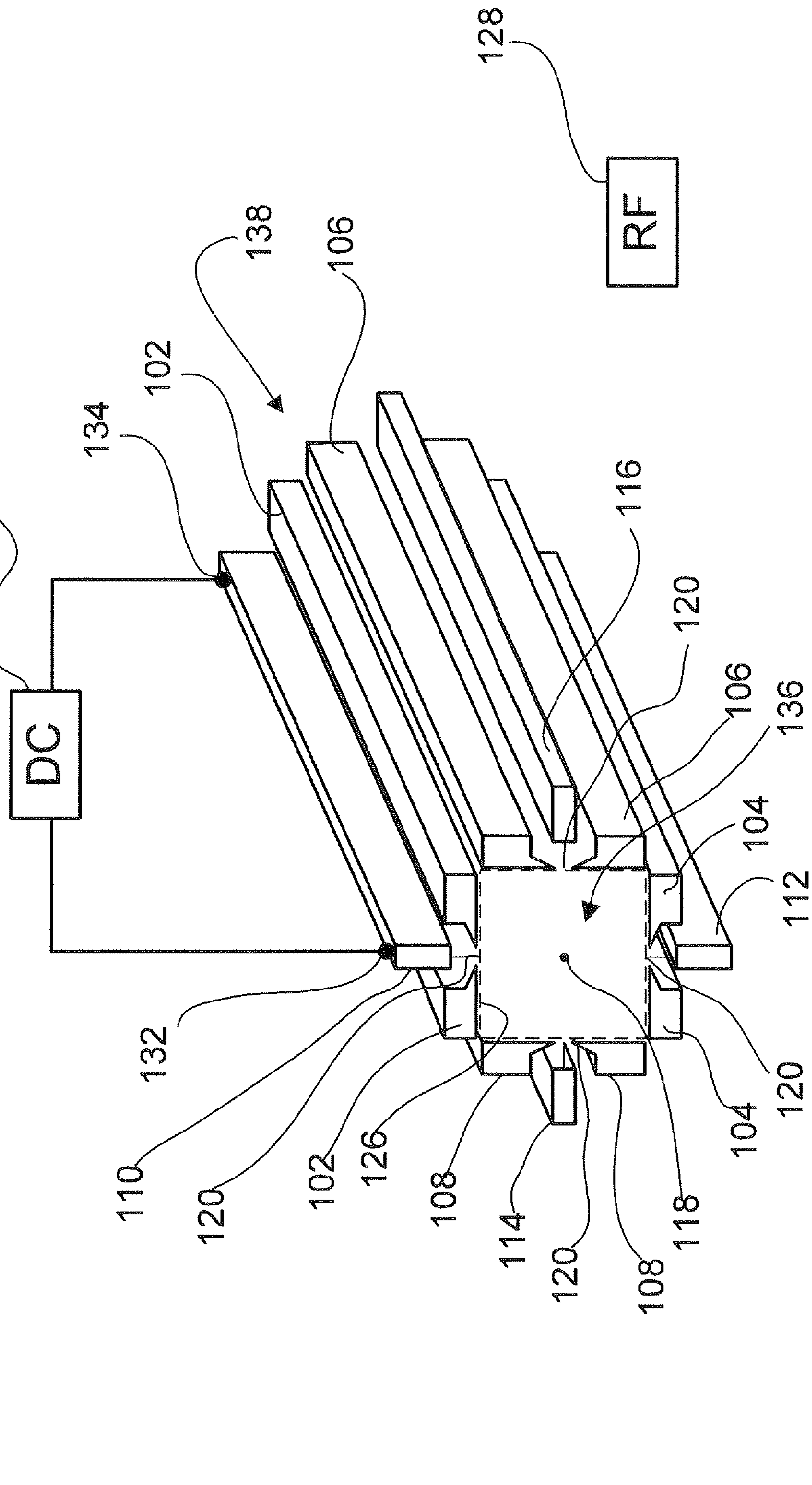




600
622
Voltage Source
620
610
Controller
618
608
624
606
Power Source
616
604
626
602

FIG. 1

FIG. 2


DC
RF
128
130
134
102
138
106
116
120
106
136
104
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132
110
120
102
126
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114
120
108
118
104
120

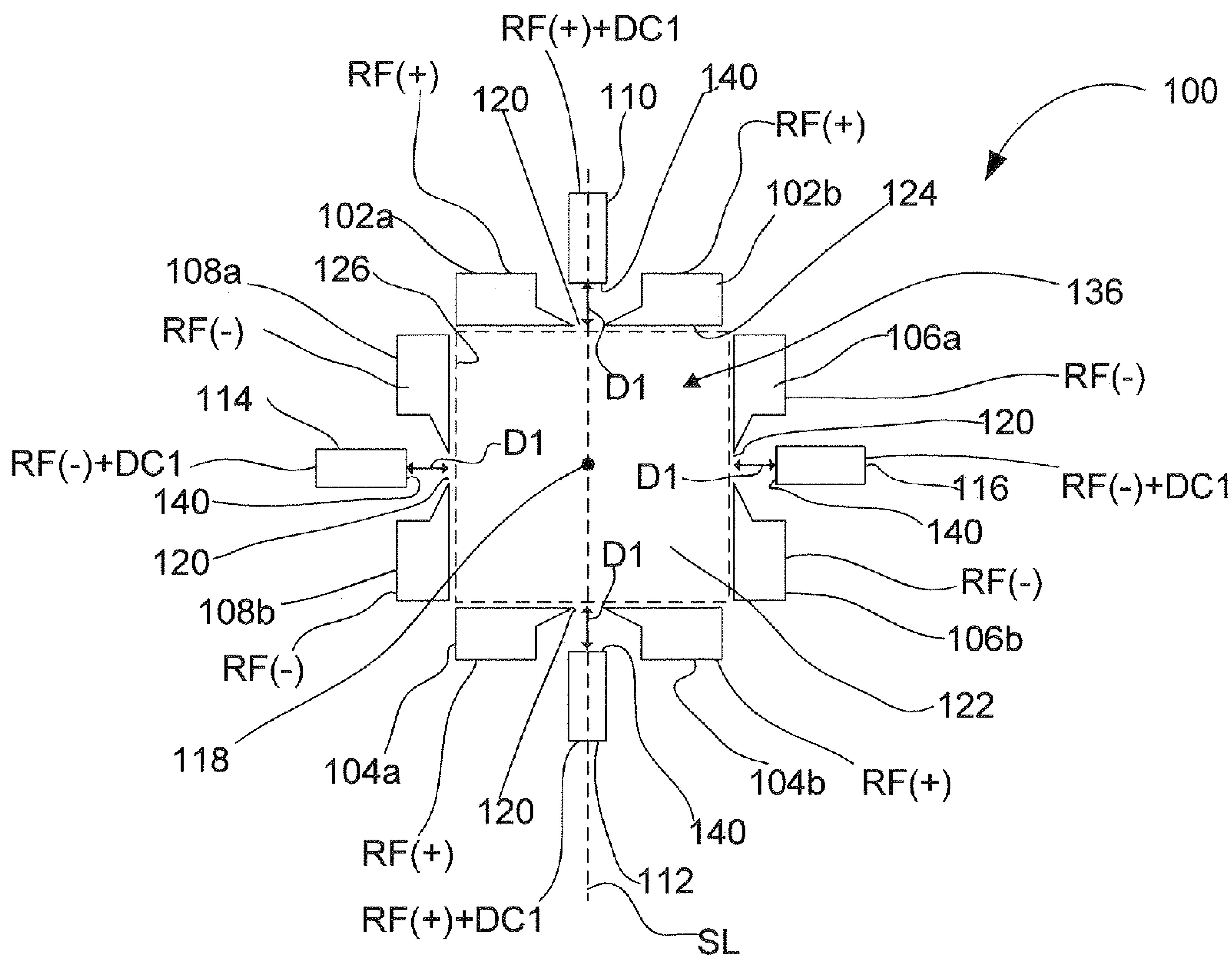

RF(+)+DC1
RF(+)
120
110
140
RF(+)
100
102a
102b
124
108a
126
136
RF(-)
106a
RF(-)
D1
114
120
D1
RF(-)+DC1
D1
116
RF(-)+DC1
140
140
120
D1
RF(-)
108b
106b
RF(-)
122
118
104a
104b
RF(+)
120
140
RF(+)
112
RF(+)+DC1
SL

FIG. 3A

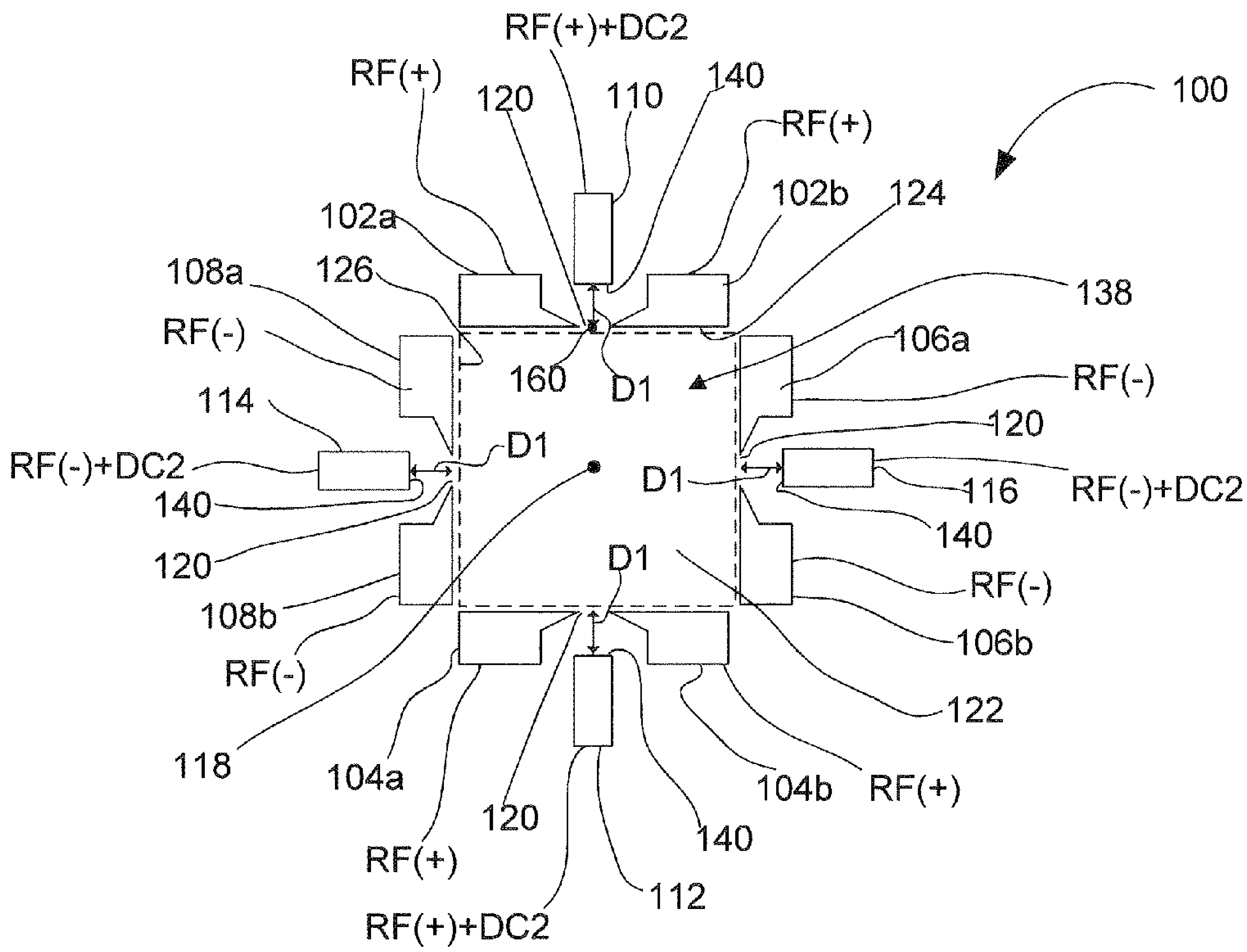

RF(+)+DC2
RF(+)
120
110
140
RF(+)
100
102a
102b
124
108a
126
138
RF(-)
106a
160
D1
RF(-)
114
120
RF(-)+DC2
D1
D1
116
RF(-)+DC2
140
140
120
D1
RF(-)
108b
106b
RF(-)
122
118
104a
104b
RF(+)
120
140
RF(+)
112
RF(+)+DC2

FIG. 3B

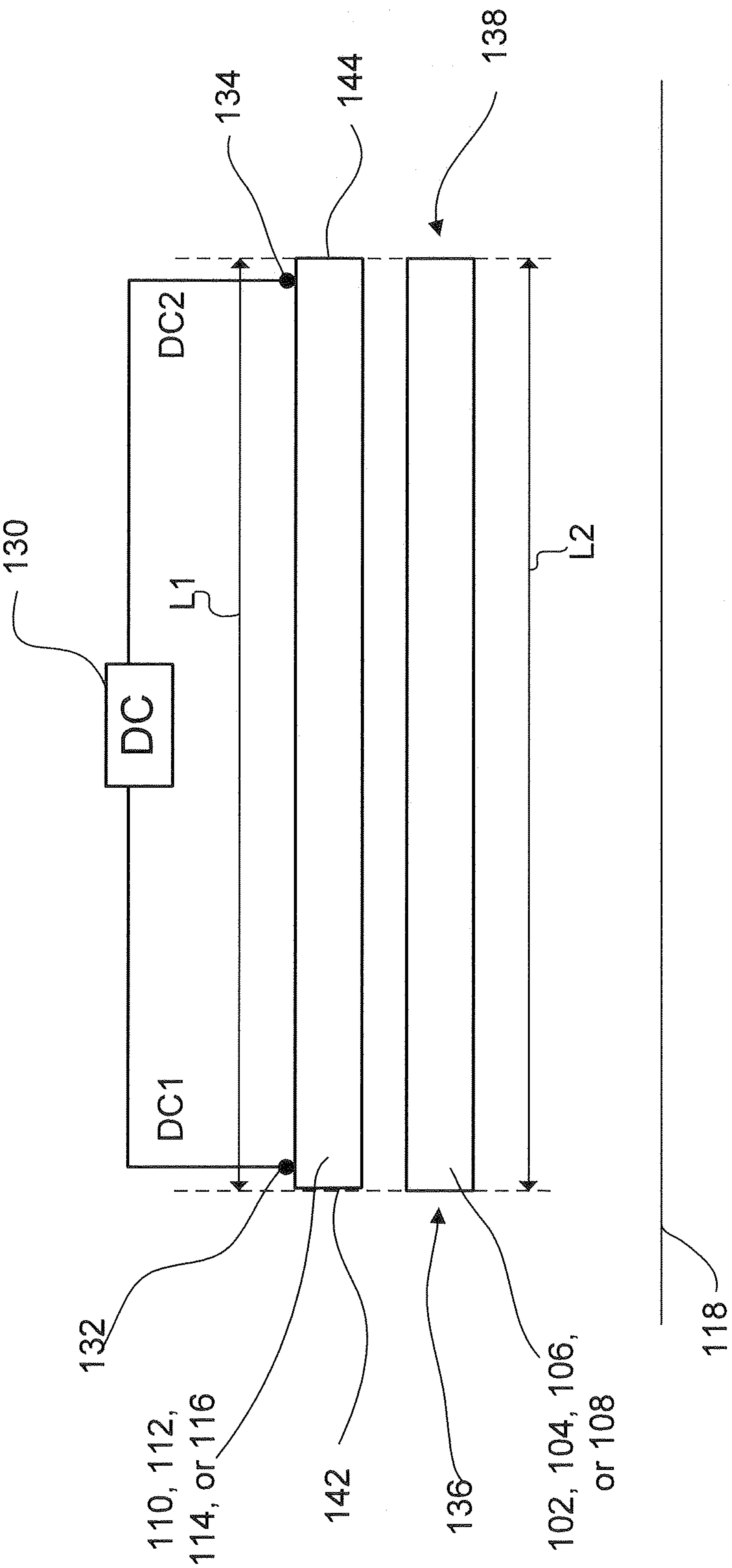

134
144
138
DC2
130
L1
L2
DC
DC1
132
118
110, 112,
114, or 116
142
136
102, 104, 106,
or 108

FIG. 4

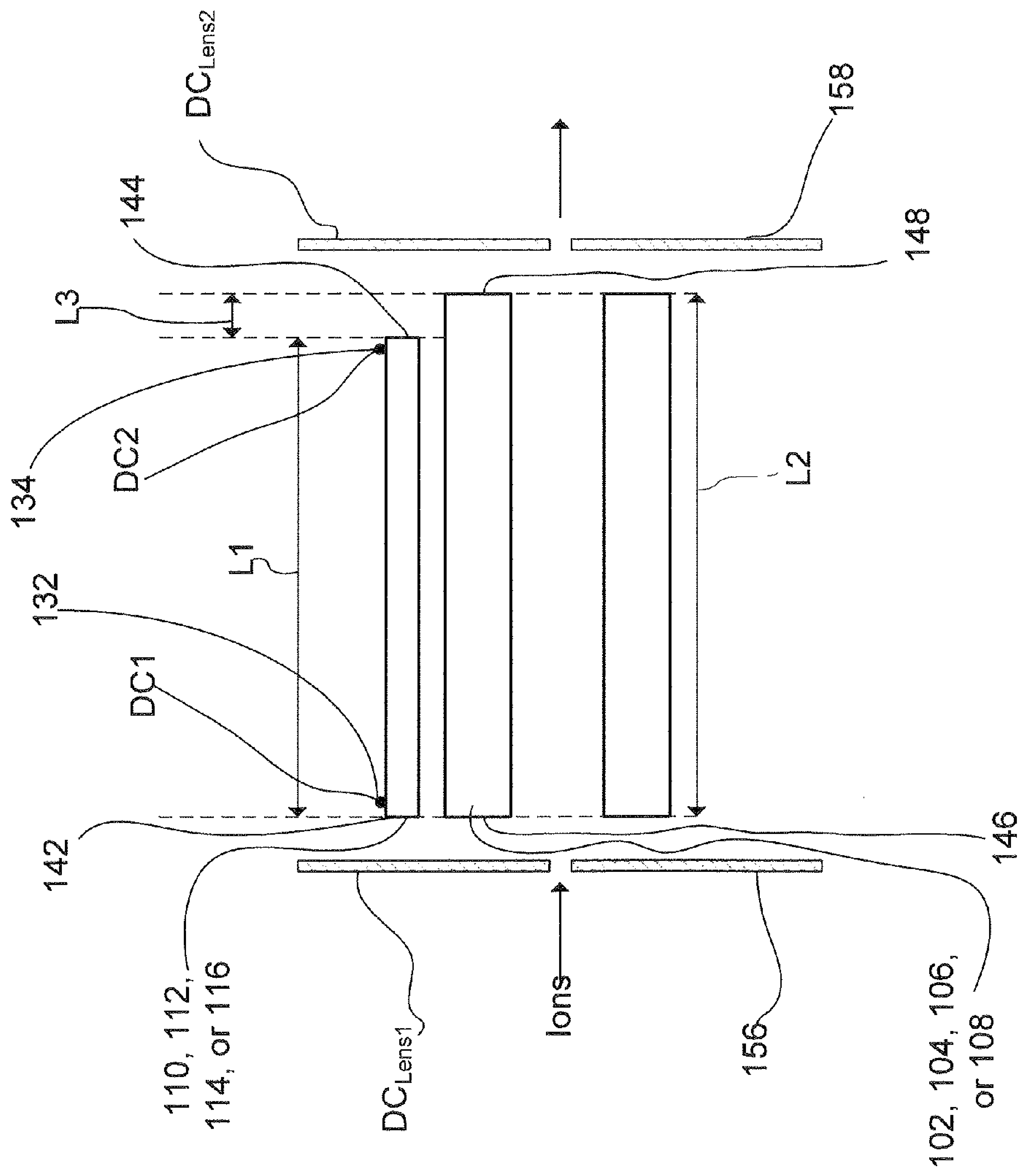

DC$_{Lens2}$
158
144
148
L3
134
DC2
L2
132
L1
DC1
142
146
110, 112,
114, or 116
DC$_{Lens1}$
Ions
156
102, 104, 106,
or 108

FIG. 5

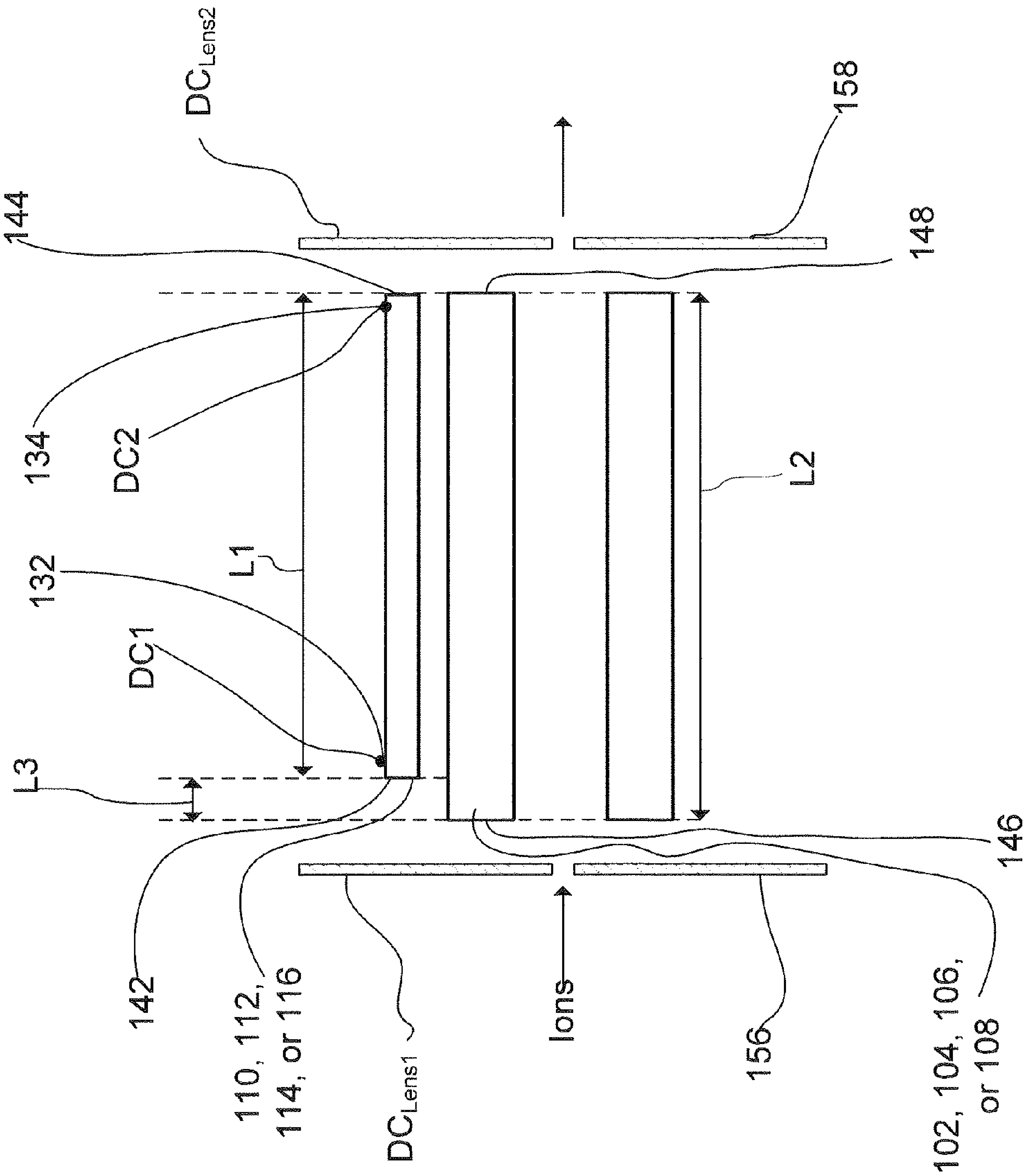

DC_Lens2
158
144
148
134
DC2
L2
132
L1
DC1
L3
146
142
110, 112, 114, or 116
DC_Lens1
Ions
156
102, 104, 106, or 108

FIG. 6

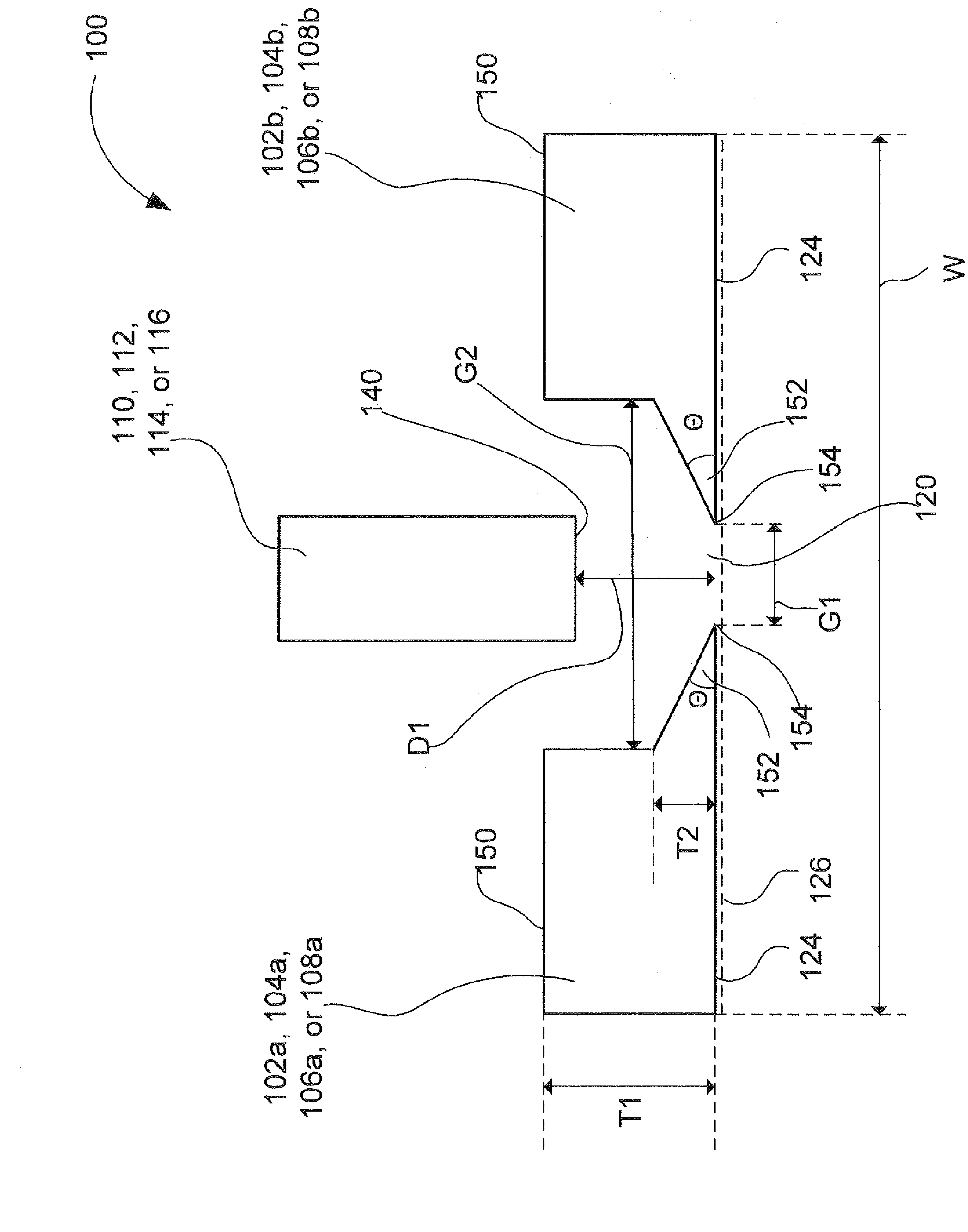
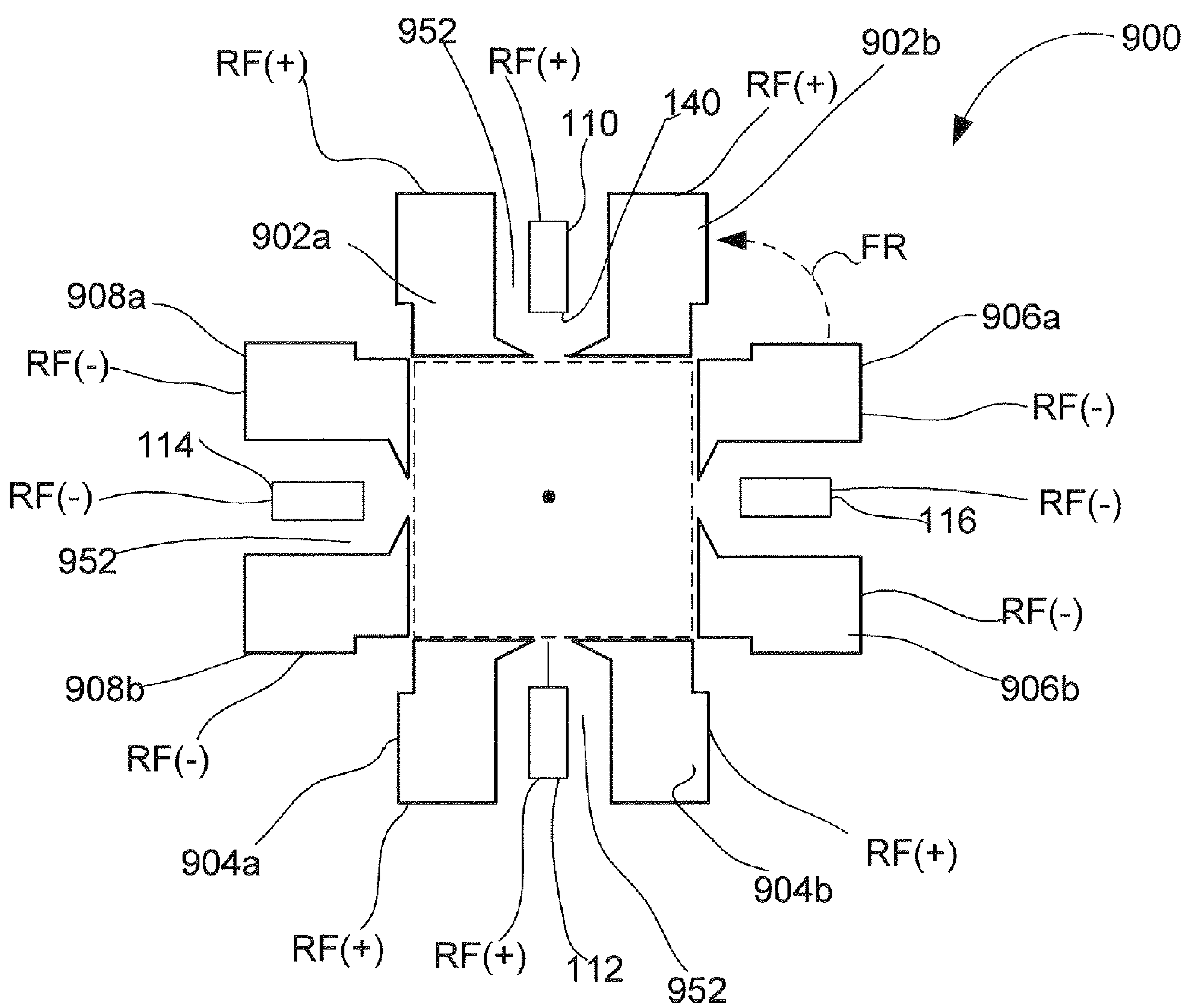

100
102b, 104b, 106b, or 108b
150
110, 112, 114, or 116
140
G2
124
W
152
θ
154
120
G1
D1
154
152
θ
T2
150
126
124
102a, 104a, 106a, or 108a
T1

FIG. 7



952
RF(+)
RF(+)
902b
900
110
140
RF(+)
902a
FR
908a
906a
RF(-)
RF(-)
114
RF(-)
RF(-)
116
952
RF(-)
908b
906b
RF(-)
904a
RF(+)
904b
RF(+)
RF(+)
112
952

FIG. 8

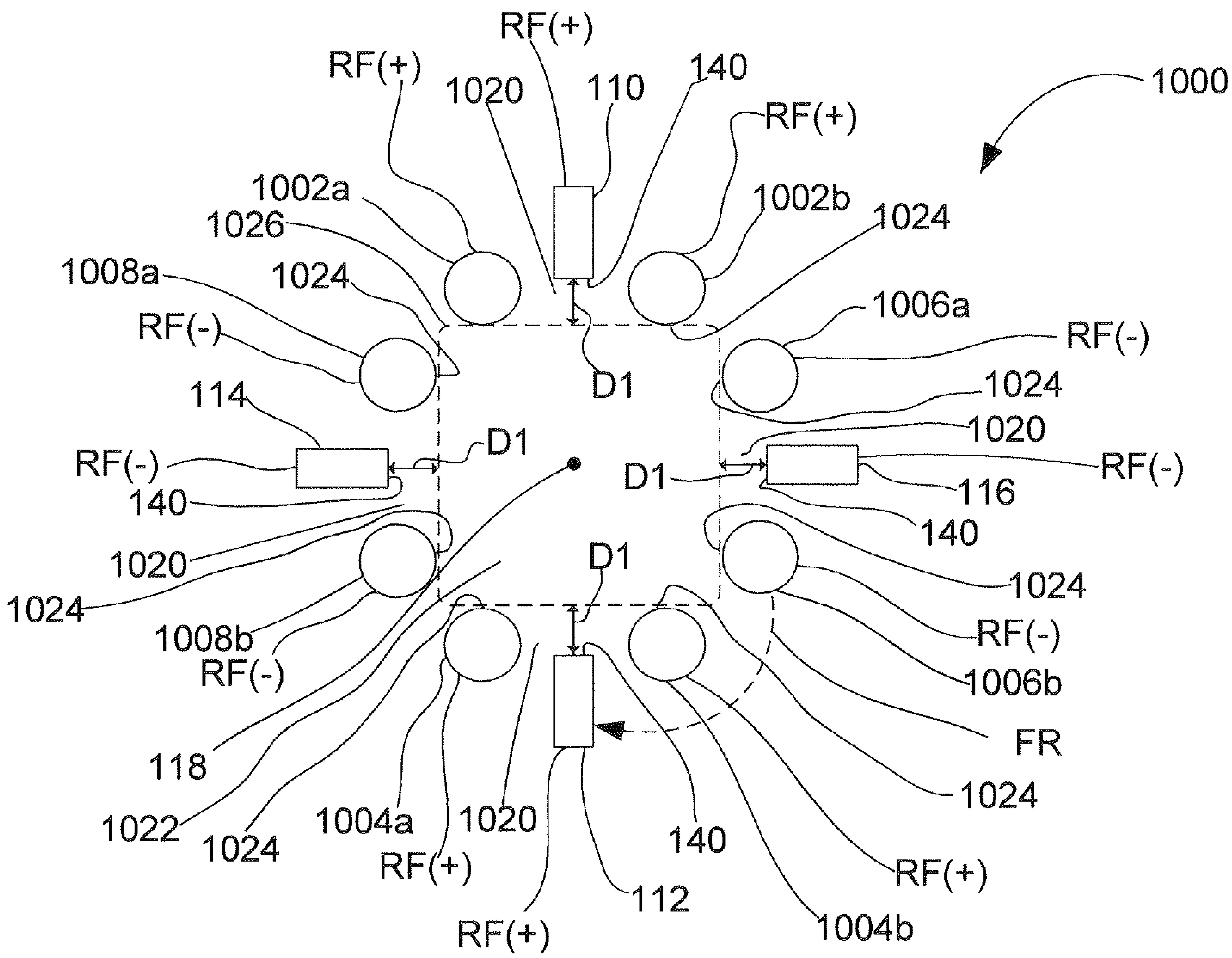

RF(+)
RF(+)
1020
110
140
RF(+)
1000
1002a
1002b
1024
1026
1008a
1024
1006a
RF(-)
RF(-)
D1
1024
114
1020
D1
RF(-)
RF(-)
D1
116
140
140
D1
1020
1024
1024
1008b
RF(-)
RF(-)
1006b
118
FR
1024
1022
1024
1004a
1020
140
RF(+)
RF(+)
112
RF(+)
1004b

FIG. 9

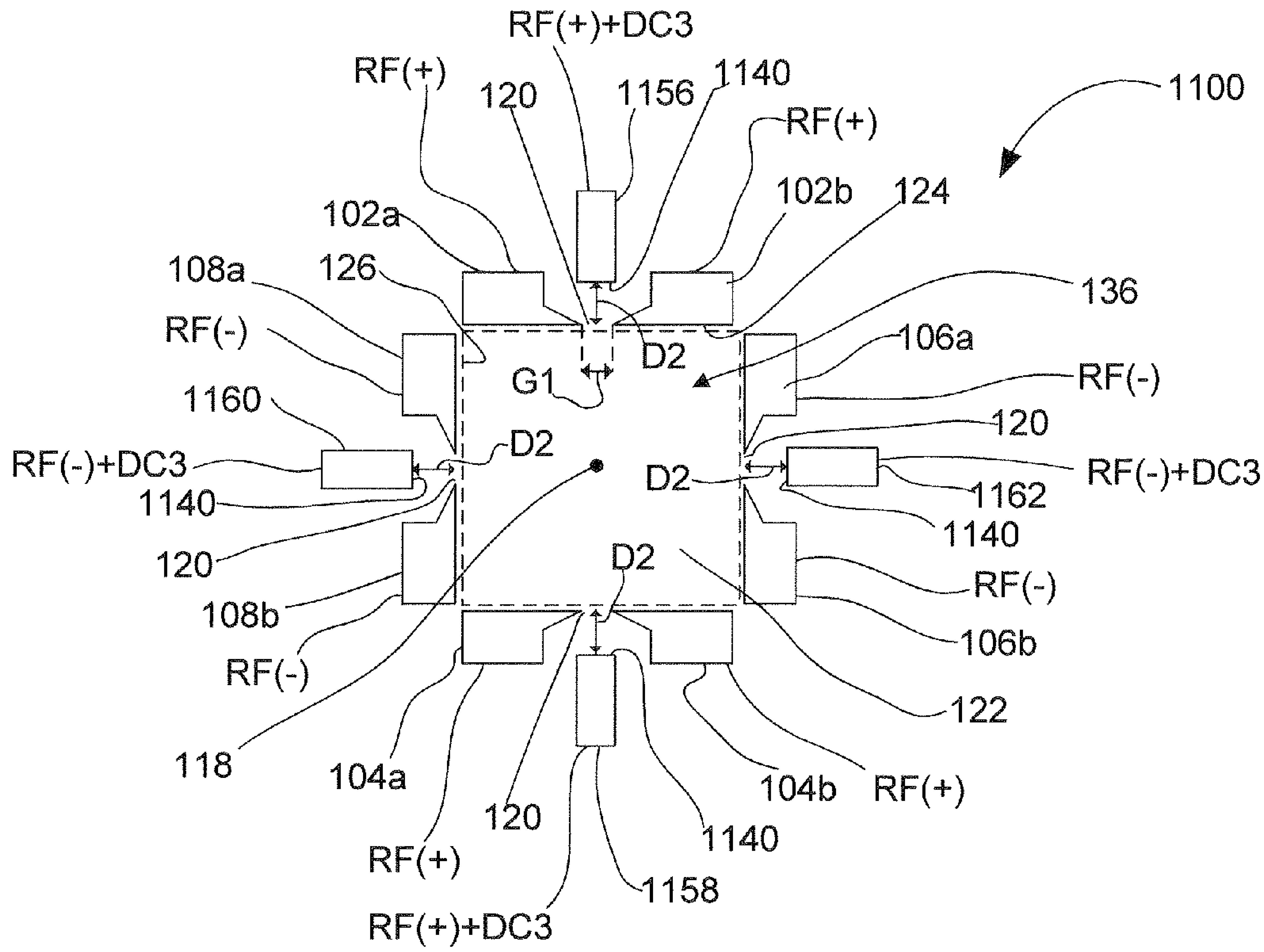

RF(+)+DC3
RF(+)
120
1156
1140
RF(+)
1100
102a
102b
124
108a
126
136
RF(-)
106a
G1
D2
RF(-)
1160
120
D2
RF(-)+DC3
RF(-)+DC3
D2
1162
1140
1140
120
D2
RF(-)
108b
106b
RF(-)
122
118
104a
104b
RF(+)
120
1140
RF(+)
1158
RF(+)+DC3

FIG. 10A

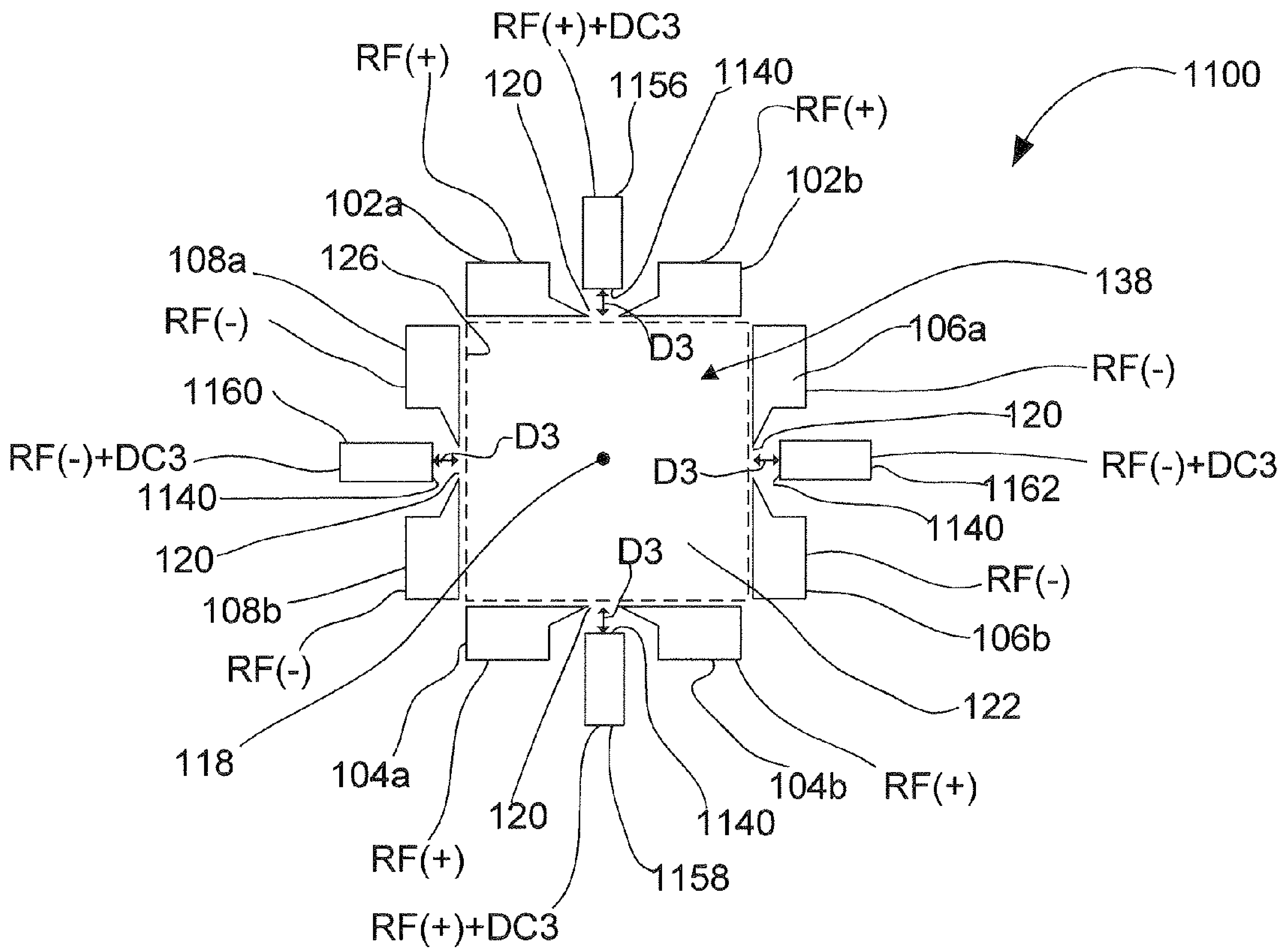

RF(+)+DC3
RF(+)
120
1156
1140
RF(+)
1100
102a
102b
108a
126
138
RF(-)
D3
106a
RF(-)
1160
120
D3
RF(-)+DC3
D3
1162
RF(-)+DC3
1140
1140
120
D3
RF(-)
108b
106b
RF(-)
122
118
104a
104b
RF(+)
120
1140
RF(+)
1158
RF(+)+DC3

FIG. 10B

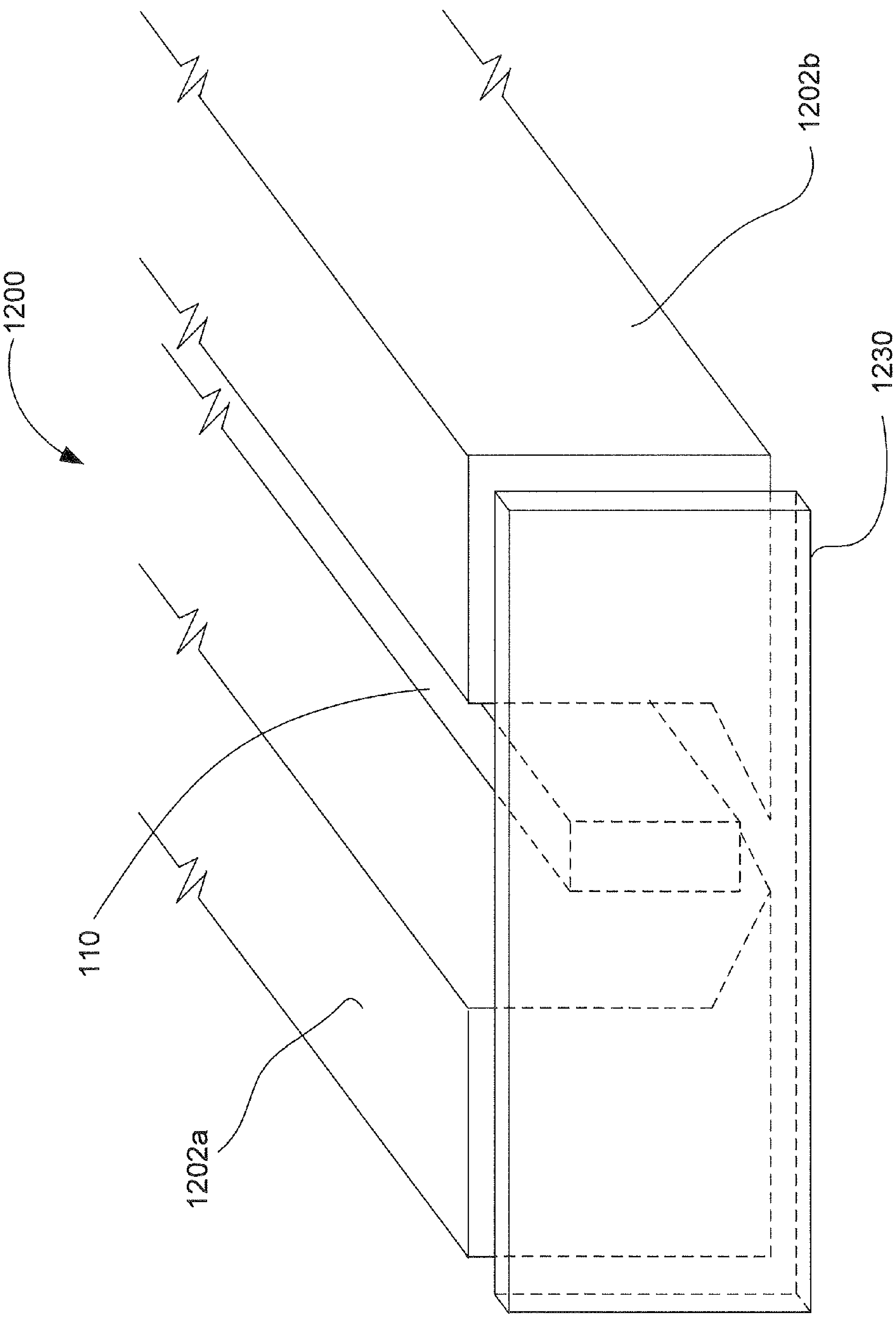
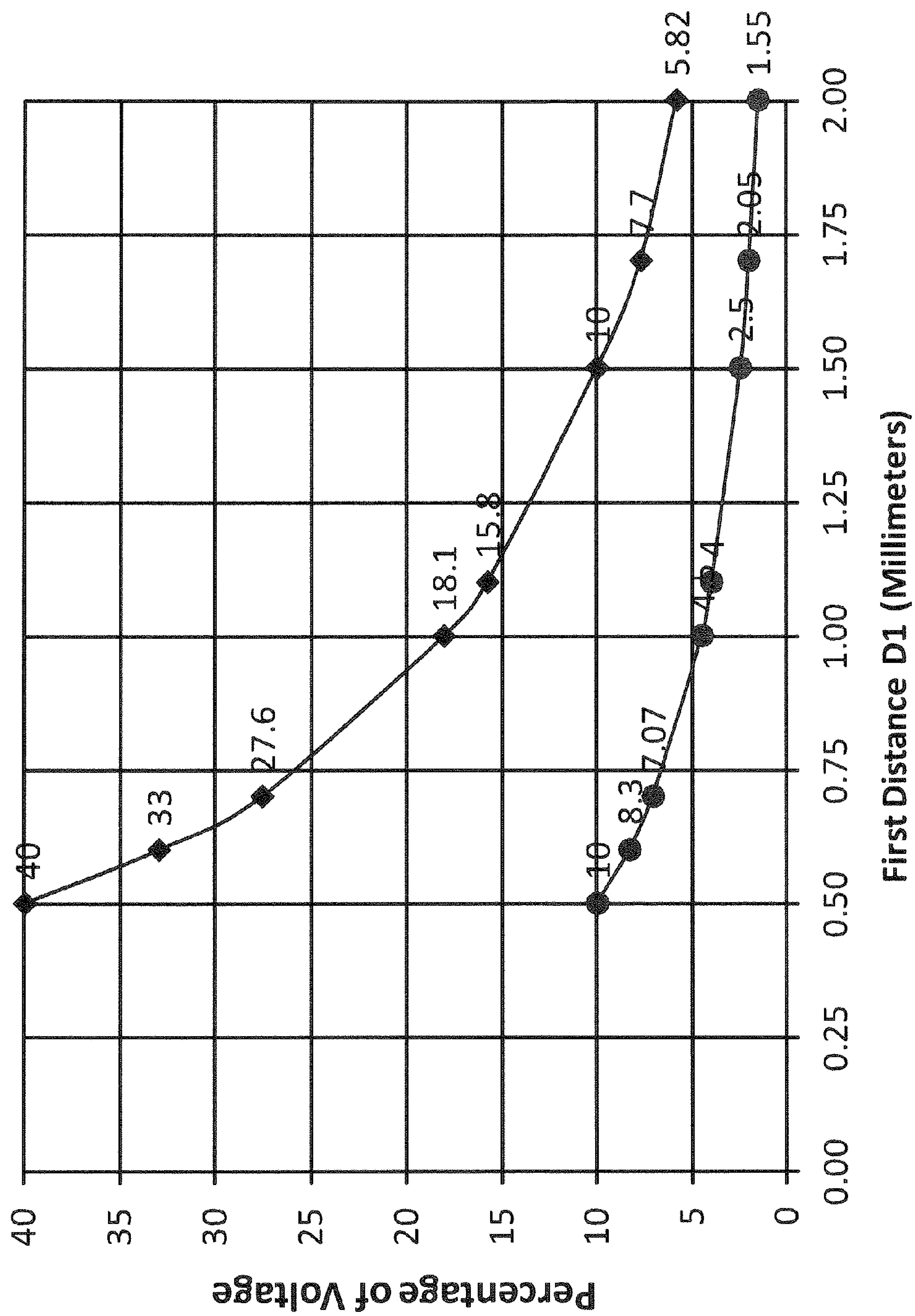


FIG. 11

FIG. 12


Percentage of Voltage
40
35
30
25
20
15
10
5
0
First Distance D1 (Millimeters)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
40
33
27.6
18.1
15.8
10
7.7
5.82
10
8.3
7.07
4.4
2.5
2.05
1.55

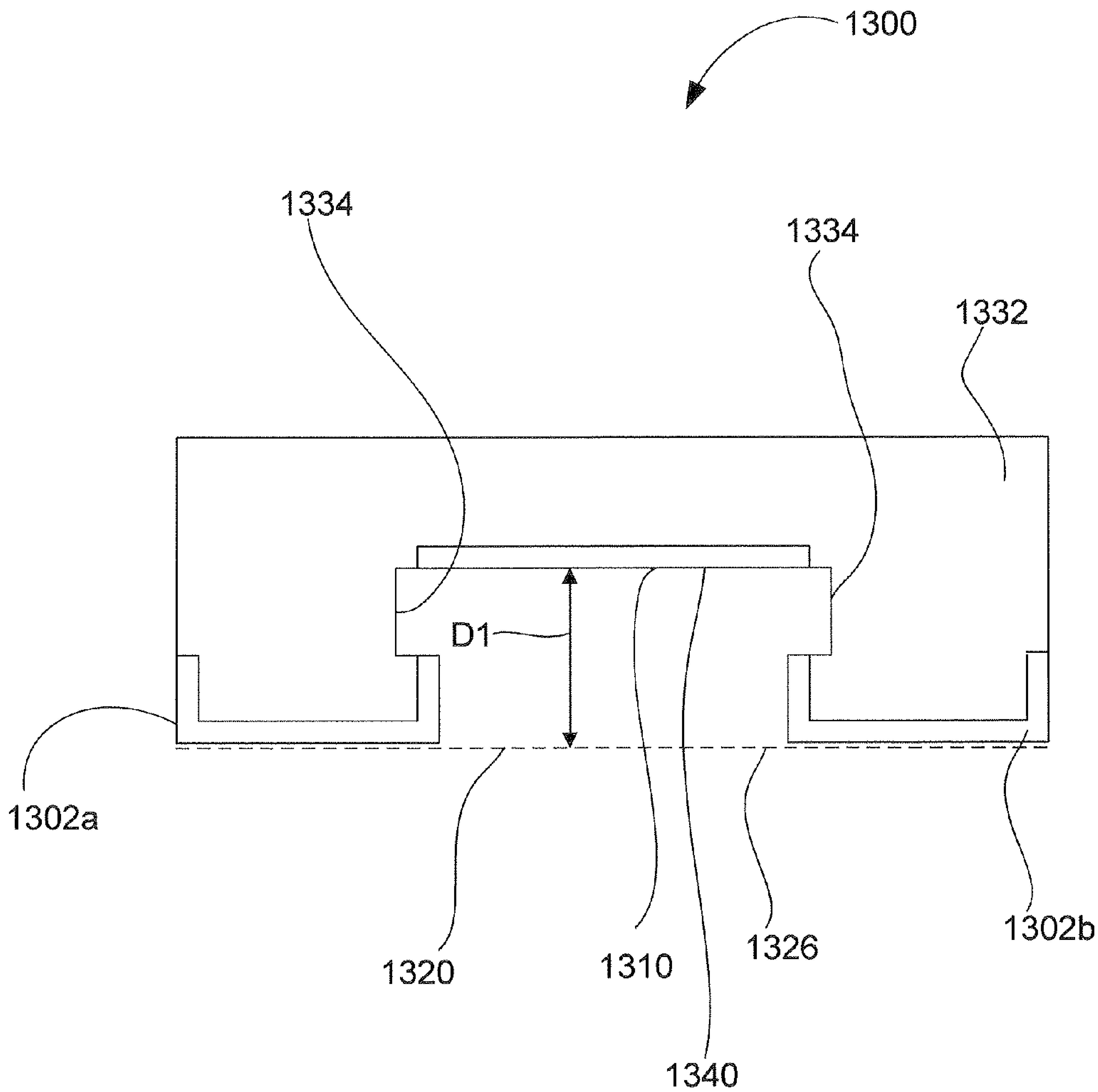


FIG. 13

MASS SPECTROMETER HAVING AN ION GUIDE WITH AN AXIAL FIELD

BACKGROUND

Mass spectrometers often employ multipole ion guides to focus and confine ions as they are transported along a path from the ionization source to the mass analyzer. Ion guides generally include a plurality of elongated electrodes (sometimes referred to as rod electrodes) to which oscillatory voltages are applied to establish a radially confining field. In addition to the ion transport function, ion guides may be employed for the radial confinement of ions in a collision cell, in which the internal volume of the ion guide is pressurized with collision gas, and ions entering the ion guide undergo fragmentation via the collision-induced dissociation mechanism.

When ion guides are located in relatively high-pressure regions of the mass spectrometer, such as in chambers adjacent the ionization source or within a collision cell, the initial axial velocities of the incoming ions are sharply reduced due to collisions between the ions and background/collision gas. This reduction in ion axial velocity results in a higher residence time within the interior of the ion guide, which may adversely affect instrument performance. More specifically, prolonged ion residence times within the ion guide may reduce sample throughput, decrease sensitivity, and impose limits on various aspects of operation. In the example of triple quadrupole mass spectrometers operated in multiple reaction monitoring (MRM) mode, slowing of ions within the collision cell or upstream ion guides will lengthen the required dwell time at each precursor-product ion transition, thereby constraining the number of different transitions that may be monitored per unit time.

In order to increase the rate at which ions are axially transported through ion guides, it is known to establish a static axial field along part or all of the ion guide length to urge ions in the direction of the ion guide exit. Various structures and methods have been disclosed in the prior art for producing an axial field of this type (see, e.g. U.S. Pat. Nos. 5,847,386; 6,111,250; 6,713,757; 7,067,802; and 7,675,031, which are hereby fully incorporated by reference herein). However, these structures and methods tend to cause distortion of the radially-confining oscillatory (e.g., radio-frequency (RF)) field, which may result in defocusing of the ion beam and consequent reduction in transmission efficiency. Applicant believes that there is a need in the mass spectrometry art for an ion guide having structures for establishing an axial field that avoids the radial-field distortion effects present in prior art devices.

SUMMARY

An ion guide may include a plurality of electrodes, a plurality of resistive inserts, a RF voltage supply, and a DC voltage supply. The plurality of electrodes may be arranged about a device centerline to form an internal volume. At least two of the electrodes may include a longitudinally extending gap. The electrodes include an inward surface facing the device centerline to form a periphery of the internal volume. The plurality of resistive inserts may be configured to be proximate to at least two of the gaps and radially aligned with respect to the device centerline. The resistive inserts may include an innermost surface that faces the device centerline where the innermost surface is a first distance from the periphery of the internal volume. The RF voltage supply may be configured to apply a RF voltage to the plurality of electrodes that establishes a RF field to radially confine ions. In an embodiment, the RF voltage supply may also be configured to apply the RF voltage to the plurality of resistive inserts. The DC voltage supply may be configured to apply a first DC voltage to a first location of the resistive insert and a second DC voltage to a second location of the resistive insert that establishes an axial electric field gradient along at least a portion of the device centerline. The second DC voltage is different than the first DC voltage and the second location is longitudinally spaced apart from the first location.

A mass spectrometer may include an ionization source, an ion guide, a mass analyzer, and a detector. The ionization source may be configured to ionize molecules. The ion guide may include a plurality of electrodes arranged about a device centerline to form an internal volume. At least two of the electrodes may include a longitudinally extending gap. The electrodes include an inward surface facing the device centerline to form a periphery of the internal volume. A plurality of resistive inserts may be configured to be proximate to at least two of the gaps and radially aligned with respect to the device centerline. The resistive inserts may include an innermost surface that faces the device centerline where the innermost surface is a first distance from the periphery of the internal volume. A RF voltage supply may be configured to apply a RF voltage to the plurality of electrodes that establishes a RF field to radially confine ions. In an embodiment, the RF voltage supply may also be configured to apply the RF voltage to the plurality of resistive inserts. A DC voltage supply may be configured to apply a first DC voltage to a first location of the resistive insert and a second DC voltage to a second location of the resistive insert that establishes an axial electric field gradient along at least a portion of the device centerline. The second DC voltage is different than the first DC voltage and the second location is longitudinally spaced apart from the first location. The mass analyzer may be configured to receive the ionized molecules from the ion guide and filter the ionized molecules so that a subset of ionized molecules having a particular mass to charge ratio passes through. The detector may be configured to receive and measure the ionized molecules from the mass analyzer.

In another embodiment of an ion guide, it includes a plurality of electrodes, a plurality of conductive inserts, a RF voltage supply, and a DC voltage supply. The plurality of electrodes may be arranged about a device centerline to form an internal volume. The internal volume can include a front end configured to allow ions to enter and a back end configured to allow ions to exit. At least two of the electrodes may include a longitudinally extending gap. The electrodes may include an inward surface facing the device centerline to form a periphery of the internal volume. The plurality of conductive inserts may be configured to be proximate to at least two of the gaps and radially aligned with respect to the device centerline. The conductive inserts may include an innermost surface that faces the device centerline. The innermost surface may include a second distance from the periphery of the internal volume at the front end of the ion guide. In addition, the innermost surface may also include a third distance from the periphery of the internal volume at the back end. The second distance at the front end being greater than the third distance at the back end. The RF voltage supply may be configured to apply a RF voltage to the plurality of electrodes that establishes a RF field to radially confine ions. In an embodiment, the RF voltage supply may also be configured to apply the RF voltage to the plurality of conductive inserts. The DC voltage supply may be configured to apply a third DC

voltage to the conductive inserts that establishes an axial electric field gradient along at least a portion of the device centerline.

A method of guiding ions in a mass spectrometer may include injecting ions into an ion guide. The ion guide may include a plurality of electrodes and a plurality of inserts. The plurality of electrodes may be arranged about a device centerline to form an internal volume. The internal volume may include a front end configured to allow ions to enter and a back end configured to allow ions to exit. At least two of the electrodes may include a longitudinally extending gap. The plurality of inserts may be configured to be proximate to at least two of the gaps. The inserts may include an innermost surface that faces the device centerline where the innermost surface includes a first distance from a periphery of the internal volume. A RF voltage may be applied to the plurality of electrodes to establish a RF field to radially confine ions. In an embodiment, the RF voltage may also be applied to the plurality of inserts. At least one DC voltage may be applied to the plurality of inserts to establish an axial electric field gradient along at least a portion of the device centerline.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate presently preferred embodiments of the invention, and, together with the general description given above and the detailed description given below, serve to explain features of the invention (wherein like numerals represent like elements). A detailed understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

FIG. **1** illustrates a schematic view of a mass spectrometer in which an ion guide constructed in accordance with an embodiment of the invention may be implemented;

FIG. **2** illustrates a simplified perspective view of an ion guide that includes segmented rectangular electrodes and resistive inserts;

FIGS. **3**A and **3**B illustrate a front and back end view, respectively, of an ion guide, in accordance with FIG. **2**;

FIG. **4** illustrates a simplified schematic view of a resistive insert and an electrode where both the resistive insert and the electrode have about the same length;

FIG. **5** illustrates a simplified schematic view of a resistive insert and an electrode where a back end of the resistive insert is recessed inward from a back end of the electrode;

FIG. **6** illustrates a simplified schematic view of a resistive insert and an electrode where a front end of the resistive insert is recessed inward from a front end of the electrode;

FIG. **7** illustrates a simplified partial end view of the ion guide of FIGS. **2** and **3**, which includes a resistive insert and two corresponding electrode portions where the resistive insert is proximate to a longitudinally extending gap;

FIG. **8** illustrates another embodiment of an ion guide where the electrodes extend outwardly to screen fringing RF fields at both ends of the ion guide;

FIG. **9** illustrates an end view of the another embodiment of an ion guide that includes eight elongated rods;

FIGS. **10**A and **10**B illustrate a front and back end view, respectively, of another embodiment of an ion guide that includes conductive inserts;

FIG. **11** illustrates a simplified partial end view of an ion guide that includes a front plate;

FIG. **12** is a graph illustrating the electric field penetration into an ion guide as a function of the first distance D**1**; and

FIG. **13** illustrates a simplified partial end view of another embodiment of an ion guide where the electrodes and resistive inserts are integrated into a PCB.

DETAILED DESCRIPTION OF EMBODIMENTS

The following detailed description should be read with reference to the drawings, in which like elements in different drawings are identically numbered. The drawings, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of the invention. The detailed description illustrates by way of example, not by way of limitation, the principles of the invention. This description will clearly enable one skilled in the art to make and use the invention, and describes several embodiments, adaptations, variations, alternatives and uses of the invention, including what is presently believed to be the best mode of carrying out the invention. As used herein, the terms “about” or “approximately” for any numerical values or ranges indicate a suitable dimensional tolerance that allows the part or collection of components to function for its intended purpose as described herein.

FIG. **1** illustrates a schematic view of a triple quadrupole mass spectrometer **600** which may incorporate one or more ion guides constructed in accordance with embodiments of the invention. Mass spectrometer **600** includes an electronic controller **618**, a power source **616** configured to supply a RF voltage to the ion guides and quadrupole mass filters, and a voltage source **620** configured to supply one or more DC voltages to various components. Mass spectrometer **600** is configured with an ionization source **626** and an inlet section **602**. Examples of ionization sources configured to ionize molecules may include electrospray ionization, chemical ionization, thermal ionization, and matrix assisted laser desorption ionization sources. In addition, mass spectrometer **600** includes ion guides **604** and **608**, as well as quadrupole mass filters **606** and **610**. As known in the art, each mass filter **606**, **610** is configured to selectively transmit a subset of ions having a particular mass to charge ratio (determined by the amplitudes of the applied RF and resolving DC voltages). Ion guide **608** is positioned within a gas-filled enclosure to form a collision cell for controlled dissociation of incoming precursor ions. Ion guides **604**, **608**, and analyzer **606**, **610** define an ion path **624** from the inlet section **602** to at least one detector **622**. The detector is configured to receive the ions transmitted along ion path **624** and responsively generate a signal representative of the number of received ions. Any number of vacuum stages may be implemented to enclose and maintain any of the devices along the ion path at a lower than atmospheric pressure. The electronic controller **618** is operably coupled to the various devices including the pumps, sensors, ion source, ion guides, collision cells and detectors to control the devices and conditions at the various locations throughout the mass spectrometer **600**, as well as to receive and send signals representing the ions being analyzed.

As discussed in the background section, it may be advantageous to establish an axial DC field within the interior of an ion guide to assist in the movement of ions therethrough and avoid the problems associated with prolonged ion retention. The prior art includes a variety of structures developed for this purpose, but many of these structures produce significant distortion in the symmetry of the radially-confining RF field.

Applicant will describe a multipole ion guide with axial electric fields that move ions through the ion guide, and has reduced distortion of RF fields. As an example, such multipole ion guides may be implemented on mass spectrometer **600** for ion guides **604** and/or **608**. FIG. **2** illustrates a simplified perspective view of an ion guide **100**, which includes a plurality of electrodes (**102**, **104**, **106**, and **108**), a plurality of resistive inserts (**110**, **112**, **114**, and **116**), a DC voltage supply **130**, and a RF voltage supply **128**. The electrodes depicted in FIG. **2** are in the form of elongated rectangles that are segmented to form a longitudinally extending gap. Ion guide **100** also includes a front end **136** configured for ions to enter and a back end **138** configured for ions to exit. When ion guide **100** is used in a collision cell, it may be further provided with a conduit (not shown) configured to add a collision gas to an internal volume so that precursor ions undergo fragmentation via the collision gas to form product ions that exit a back portion of the ion guide under the influence of the axial electric field gradient. The following will describe in more detail the components and the configuration of ion guide **100**.

While the foregoing paragraph describes the implementation of ion guide **100** within a triple quadrupole mass spectrometer **600**, it should be understood that this description is provided by way of example only, and does not limit the invention to operation in any particular environment. Those skilled in the art will recognize that embodiments of the invention may be beneficially incorporated into any number of mass spectrometer types and architectures.

FIGS. **3**A and **3**B illustrate, respectively, a front end view and a back end view of ion guide **100**. Each of the four electrodes (**102**, **104**, **106**, and **108**) include a longitudinally extending gap **120** that splits the electrode into two separate portions displaced from one another. Within a particular electrode, a first portion can be referred to with the suffix "a" and the other respective corresponding second portion can be referred to with the suffix "b." As illustrated in FIG. **3**, a first electrode portion can be **102***a*, **104***a*, **106***a*, and **108***a*, and a respective corresponding second electrode portion can be **102***b*, **104***b*, **106***b*, and **108***b*. As illustrated in FIGS. **2** and **3**, the longitudinal gap **120** extends the entire length of the electrode splitting it into separate portions. However, in an alternative embodiment, the longitudinally extending gap does not have to extend the entire length of the electrode and may partially split the electrode into two branches so that they are still electrically connected along a section of an internal volume of the ion guide.

It should be noted that although ion guide **100** is depicted as having four longitudinally extending gaps **120**, an alternative embodiment may include only two gaps so long as they are in an opposing relation with respect to the device centerline. Additionally, where the alternative embodiment has four electrodes, the two remaining electrodes will not have a longitudinally extending gap and will be in an opposing relation with respect to the device centerline.

Referring back to FIGS. **2** and **3**, the plurality of electrodes (**102**, **104**, **106**, and **108**) can be arranged about a device centerline **118** to form an internal volume **122**. The device centerline **118** can be an approximately straight line that is disposed in a center portion of the internal volume that intersects both front end **136** and back end **138** of the ion guide. In an embodiment, the plurality of electrodes can be symmetrically arranged about the device centerline. The plurality of electrodes and the plurality of resistive inserts may both include an approximately straight longitudinal axis that are approximately parallel to the device centerline. Alternatively, the device centerline may include a curvature where the plurality of electrodes and the plurality of resistive inserts both include a curved longitudinal axis that corresponds to the curvature of the device centerline.

FIG. **7** illustrates a simplified partial end view of ion guide **100** of FIGS. **2** and **3**, which includes a resistive insert (**110**, **112**, **114**, or **116**) and two corresponding electrode portions (**102**, **104**, **106**, or **108**, both "a" and "b") where the resistive insert is proximate to a longitudinally extending gap **120**. The electrodes can include an inward surface **124** facing the device centerline **118** to form a periphery **126** of internal volume **122**. The periphery **126** is denoted as a dotted line in FIGS. **2**, **3**, and **7**. The aggregate of inward surfaces **124** form an outline that defines periphery **126** of the internal volume. Electrode materials may include stainless steel, Invar, or gold coated glass. Invar is a nickel steel alloy that has a relatively low coefficient of thermal expansion (e.g., about 1.2 ppm/° C.). The electrode materials may have a resistivity ranging from about 1 to 10×10^{-7} Ωm.

The inward electrode surface **124** in FIGS. **2**, **3**, and **7** is essentially flat with gap **120** in between the electrode portions. However, the inward surface does not have to be flat and may be a different shape such as, for example, a curved surface from a cylinder and a hyperbolic surface. In an embodiment, the electrodes may be elongated rods where the rods can be cylinders, squares, rectangles, or other shape suitable for generating RF fields that can guide ions.

The plurality of resistive inserts (**110**, **112**, **114**, and **116**) are configured to be proximate to each of the gaps **120**, as illustrated in FIGS. **2**, **3**, and **7**. In addition, the resistive inserts (**110**, **112**, **114**, and **116**) are also radially aligned with respect to device centerline **118**. In an embodiment, the resistive inserts (**110**, **112**, **114**, and **116**) are arranged in pairs in an opposing format with respect to the device centerline **118**. For example, a pair of resistive inserts (**110** and **112**) is arranged such that an approximately straight line (denoted by dotted line SL) intersects the two resistive inserts (**110** and **112**) and the device centerline **118**, as illustrated in FIG. **3**A. In addition, the approximately straight line SL goes through the gaps proximate to the pair of respective inserts (**110** and **112**) without touching the proximate electrodes (**102** and **104**). In an embodiment, the plurality of resistive inserts are symmetrically arranged about the device centerline. It should be noted that although ion guide **100** is depicted as having four resistive inserts that are proximate to four longitudinally extending gaps **120**, an alternative embodiment may include only two resistive inserts that are proximate to two respective gaps so long as they are in an opposing format with respect to the device centerline.

Referring back to FIGS. **3** and **7**, the resistive inserts (**110**, **112**, **114**, and **116**) can include an innermost surface **140** that faces device centerline **118** where innermost surface **140** is a first distance D**1** from periphery **126** of internal volume **122**. The innermost surface **140** is an approximately flat portion of the resistive insert that is closest to and facing the device centerline **118**, as is illustrated in FIG. **7**. In an embodiment, the innermost surface of the resistive insert may represent the portion closest to the periphery of the internal volume. The innermost surface does not have to be flat and may be a different shape such as, for example, a curved surface from a cylinder and a hyperbolic surface. In an embodiment, the resistive insert may be elongated rods where the rods can be cylinders, squares, rectangles, or other shape suitable for generating an axial field gradient that can guide ions.

An insert proximate to the gap may represent that a location of the insert is next to, very close in space to, neighboring, or adjacent to the gap. In another embodiment, the resistive insert may be proximate and, in addition to, be partially disposed within the gap. The proximate location of the resistive with respect to the gap can be configured so that a sufficiently strong electric field gradient is generated for moving along ions along the device centerline in order to meet instrument performance targets. In an embodiment, the proximate inserts need to be sufficiently close to the gap so that a sufficiently strong axial electric field can be created to move ions along the device centerline. The magnitude of the first distance D**1** range may be influenced by other factors such as DC voltage, electrode thickness, and gap distance.

In an embodiment, first distance D**1** can be approximately uniform for the entire length of the resistive insert, as illustrated in FIGS. **3**A and **3**B. First distance D**1** may range from about 0.3 millimeters to about 2 millimeters, and preferably range from about 0.5 millimeter to about 1.0 millimeters. First distance D**1** may be sufficiently large so that the resistive insert is not exposed to a RF field gradient that could cause it to dissipate power. However, first distance D**1** may be sufficiently small so that the strength of the electrical field effectively transmitted through gap **120** can effectively influence ion movement. It should be noted that configuring a uniform first distance D**1** for the length of the resistive insert provides for a simple to make ion guide design and alignment.

FIG. **12** is a graph illustrating the electric field penetration as a function of the first distance D**1**. More particularly, the graph shows the relative magnitude of DC electric potential (the effective field strength) at particular locations in an ion guide. For each value of first distance D**1**, the graph shows the effective field strength at a center point of the gap at the periphery of the internal volume (diamonds) and also at device centerline **118** (filled circles). The center point of the gap at the periphery of the internal volume for exemplary purposes is denoted as a point **160** in FIG. **3**B. The Y-axis in FIG. **12** shows the effective electric field strength as a percentage of the applied DC potential at the resistive insert. In general, the effective electric field strength decreases as the first distance increases.

The resistive insert may be a normal semiconductor, resistive material coated insulator, or a composite material such as resin impregnated with electrically conductive particles (carbon filled PEEK for instance). In an embodiment, the plastic may be an ESd (electrostatic dissipative) material such as, for example, the commercially available Semitron **480** (reinforced polyetheretherketone (PEEK)). The resistive insert may have a surface resistivity ranging from about 10^2 to about 10^{10} ohms per square, and preferably range from about 10^6 to about 10^{10} ohms per square. In an alternative embodiment, the resistive insert may be in the form of a resistive material disposed on a surface of a printed circuit board (PCB). It should be noted that the resistive insert has a simple configuration; it is one continuous part and does not have multiple segmentations with numerous electrical connections (i.e., >2 per insert) to a DC voltage supply.

The resistive insert may have a relatively uniform resistivity along its length so that a gradient field has relatively low distortion. In an embodiment, the resistivity may have a relative variation (about one standard deviation) ranging from about 5% to about 30%, and preferably be less than about 10% for a typical insert having a length of about 10 centimeters.

DC voltage supply **130** may be electrically connected to the plurality of resistive inserts via wires. In an embodiment, a hole may be drilled into the resistive insert and a conductive epoxy, or any other conductive adhesive may be used to secure the wire directly into the resistive insert. In another embodiment, a clip can be used to secure the wire into the hole in the resistive insert or to the body of the resistive insert.

Referring back to FIG. **2**, RF voltage supply **128** is configured to apply a RF voltage to the plurality of electrodes (**102**, **104**, **106**, and **108**). Note that for purposes of simplifying the drawing, the electrical connections of the RF voltage supply **128** to the plurality of electrodes are not shown in FIG. **2**. The application of the RF voltage will establish a RF field to radially confine ions along device centerline **118**. In an embodiment, an identical RF voltage can be applied to first electrode portion **102***a* and corresponding second electrode portion **102***b*. Since approximately the same polarity, voltage, and frequency are applied to both electrode portions **102***a* and **102***b*, they effectively behave as one electrode **102**. In an embodiment, a RF voltage having a first RF potential RF(+) can be applied to one opposed electrode set (**102***a*, **102***b*, **104***a*, and **104***b*), and a second RF potential RF(−) can be applied to another opposed electrode set (**106***a*, **106***b*, **108***a*, and **108***b*), as shown in FIGS. **3**A and **3**B. The second RF potential RF(−) may have an amplitude and frequency identical to RF(+), but with a phase opposite to RF(+). RF voltage may include a voltage ranging from about 100 to about 1000 volts and a frequency ranging from about 0.1 MHz to about 5 MHz. Although the RF voltages are expressed in positive numbers, the RF voltage values could also be negative in polarity.

In an embodiment, the RF voltage supply **128** can also be configured to apply a RF voltage to the plurality of electrodes (**102**, **104**, **106**, and **108**) and the plurality of resistive inserts (**110**, **112**, **114**, and **116**). A RF voltage having a first RF potential RF(+) can be applied to electrodes **102***a*, **102***b*, **104***a*, and **104***b*, and resistive inserts **110** and **112**, as shown in FIGS. **3**A and **3**B. In addition, a RF voltage having a second RF potential RF(−) can be applied to electrodes **106***a*, **106***b*, **108***a*, and **108***b*, and resistive inserts **114** and **116**, as shown in FIGS. **3**A and **3**B.

It should be noted that the resistive inserts in ion guide **100** are placed in an approximately zero gradient RF region. This is a result of the resistive inserts being placed proximate to the gap of corresponding electrode portions where the same RF potential is applied to the electrode portions and the resistive insert. By placing the inserts in an approximately zero gradient RF region, there is little change in observed capacitance and RF frequencies in the ion guide with and without the application of an axial electric field gradient. It should be noted that the resistive inserts can be made with relatively high dissipative materials for generating drag fields in ion guides when the resistive inserts are disposed in an approximately zero gradient RF region.

Under circumstances where an insert is placed between two RF electrodes that have different RF potentials, a strong RF gradient can exist and cause power to dissipate into the insert. For example, locating a resistive insert in between electrode portions **102***b* and **106***a* would cause the resistive insert to be in a relatively high RF gradient field. This configuration can cause a RF power dissipation in the resistive plastic. During frequency tuning, this can appear as degradation in the measured signal in the form of significant tune curve peak broadening and higher RF current consumption. A possible result of this power dissipation can be heat buildup and destruction of the insert. For the situation where the inserts are exposed to strong RF gradients or fringing RF fields, applicants believe that the inserts need to be constructed with materials having relatively low dissipation loss factors. In turn, applicants believe that there are a limited number of materials that can be used for resistive inserts that have the appropriate resistivity, dissipative loss factor, and uniform resistivity simultaneously. However, for the embodiments where inserts are disposed proximate to the gap in an approximately zero gradient RF region, applicants believe that many other materials could be used as an insert because materials with higher dissipation loss factors could be used.

In the embodiment where the resistive inserts are disposed proximate to the gap, the dissipation loss factor of the resistive insert may be greater than about 0.01, and be about 0.266 at 1 MHz for Semitron **480** in the embodiment.

DC voltage supply **130** is configured to apply a DC voltage difference along each one of the plurality of resistive inserts (**110**, **112**, **114**, and **116**). More particularly, DC voltage supply can apply a first DC voltage DC**1** to a first location for each of the resistive inserts (**110**, **112**, **114**, and **116**) and a second DC voltage DC**2** to a second location for each of the resistive inserts, as shown in FIGS. **3**A and **3**B. For purposes of simplicity, the electrical connections from the DC voltage supply **130** to the first and second location of resistive insert **110** is illustrated in FIG. **2**, but not to the other resistive inserts **112**, **114**, and **116**. The application of the DC voltages can establish an axial electric field gradient along at least a portion of the device centerline. The second DC voltage needs to be different than the first DC voltage and the second location needs to be longitudinally spaced apart from the first location. It should be noted that both DC and RF voltages can be applied to the resistive insert, as is shown in FIGS. **3**A and **3**B. In an embodiment, the difference in the applied voltage from the first location to the second location along the device centerline (e.g., (DC−DC**2**)/L**1**) ranges from about 0.5 V/cm to about 5 V/cm. For example, where L**1** is about 10 centimeters, the difference in the applied voltage from the first location to the second location ranges from about 5 Volts to about 50 Volts.

It should be noted that the arrangement of resistive inserts in ion guide **100** with the DC voltage difference provides a low distortion in RF field, with the distortion appearing in the dodecapolar non-linear term. In contrast, the tilted and tapered electrode configurations described in U.S. Pat. Nos. 5,847,386 and 6,111,250 provide a higher distortion in RF field where the distortion appears in the octupolar term. Electrode geometries that have rotational symmetry along a device centerline will have less RF distortion as compared to electrodes geometries that do not have rotational symmetry such as, for example, the tilted and tapered electrode configurations. As a result, ion guide **100** and others described herein, that have rotational symmetry with respect to the device centerline, provide RF fields with relatively lower distortion caused by the octupolar field component. Reduced contribution of this component to the RF field will diminish negative effects of non-linear resonances on mass dependency in ion transmission.

FIG. **4** illustrates a simplified schematic view of an electrode (**102**, **104**, **106**, or **108**) and a resistive insert (**110**, **112**, **114**, or **116**) where the length of the electrode and resistive insert are about the same. Although ion guide **100** is shown with four electrodes and four resistive inserts, only one electrode and one insert is shown for illustrative simplicity in FIG. **4**. The resistive insert can include a first length L**1** and the electrodes can include a second length L**2**. Both first length L**1** and second length L**2** can be about the same and approximately parallel to the device centerline **118**. First length L**1** and second length L**2** can both be approximately bounded at front end **136** and back end **138** of the ion guide so that they approximately correspond with a length of the internal volume. First length L**1** and second length L**2** may range from about 2 centimeters to about 20 centimeters. In an embodiment, a first DC voltage DC**1** can be applied to first location **132** adjacent to a front end **142** of the resistive insert. A second DC voltage DC**2** can be applied to second location **134** adjacent to a back end **144** of the resistive insert.

Now that the situation has been described where the insert and electrode have about the same length, the following will describe embodiments where the resistive insert length L**1** is less than the electrode length L**2**. More particularly, a back end of the resistive insert can be recessed inward, as illustrated in FIG. **5**, and alternatively the front end of the resistive insert can be recessed inward, as illustrated in FIG. **6**. Where the back end of the resistive insert is recessed inward, a "push" mechanism is required to move ions along the ion guide. In contrast, where the front end of the resistive insert is recessed inward, a "pull" mechanism is required to move ions along the ion guide.

FIG. **5** illustrates a simplified schematic view of a resistive insert (**110**, **112**, **114**, or **116**) and an electrode (**102**, **104**, **106**, or **108**) where a back end **144** of the resistive insert is recessed inward from a back end **148** of the electrode. The first length L**1** may be shorter than the second length L**2** by a distance ranging from about 2 millimeters to about 5 millimeters. This distance representing the inward recess of the resistive insert may also be referred to as third length L**3**. Similar to FIG. **4**, both first length L**1** and second length L**2** can be approximately parallel to the device centerline **118**. In accordance with FIG. **5**, the resistive insert is arranged so that a front end **142** of the resistive insert is approximately aligned with a front end **146** of the electrodes. However, a back end **144** of the resistive insert is not aligned with a back end **148** of the electrodes. The first location **132** is adjacent to front end **142** of the resistive insert and the second location **134** is adjacent to back end **144** of the resistive insert.

Referring back to FIG. **5**, the embodiment also includes a first lens **156** and a second lens **158**. The first lens **156** is located adjacent to the front end **146** of the electrodes and second lens **158** is located adjacent to the back end **148** of the electrodes. Because the resistive insert is recessed inward at the back end, the ions will be "pushed" through the ion guide so long as the appropriate magnitude and polarity of DC potentials are applied to the first lens DC_{Lens1}, first location DC**1**, second location DC**2**, the electrodes DC_{main}, and preceding ion optics. DC_{Lens1} refers to the DC voltage applied to first lens **156**. DC_{main} refers to the DC voltage applied to the electrodes (**102**, **104**, **106**, and **108**). For the scenario where the ions are positive, then the following condition needs to be satisfied $DC1>DC2>DC_{main}$ for push action so that the ions are sufficiently energized to be pushed through the ion guide. In view of relationship $DC1>DC2>DC_{main}$, an extra local potential barrier occurs on the multipole axis near the DC**1** location. Voltages on the preceding ion optics, DC_{Lens1}, and DC_{main} are to be set accordingly to provide ions with sufficient energy to compensate for this potential barrier. This voltage difference may be about 0.5 Volts to about 5 Volts.

FIG. **6** illustrates a simplified schematic view of a resistive insert (**110**, **112**, **114**, or **116**) and an electrode (**102**, **104**, **106**, or **108**) where a front end **142** of the resistive insert is recessed inward from a front end **146** of the electrode. Third length L**3** may approximately correspond as the distance between front end **142** of the resistive insert and the front end **146** of the electrode. In accordance with FIG. **6**, the resistive insert is arranged so that a back end **144** of the resistive insert is approximately aligned with a back end **148** of the electrodes. However, a front end **142** of the resistive insert is not aligned with a front end **146** of the electrodes.

Referring back to FIG. **6**, the embodiment also includes a first lens **156** and a second lens **158** that is configured in a manner similar to the embodiment in FIG. **5**. For the situation where the resistive insert is recessed inward at the front end, this will cause ions to be "pulled" through the ion guide so long as the appropriate magnitude and polarity of DC potentials are applied to the first location DC**1**, second location DC**2**, second lens DC_{Lens2}, the electrodes DC_{main}, and downstream ion optics. DC_{Lens2} refers to the DC voltage applied to second lens **158**. For the scenario where the ions are positive and both DC**1** and DC**2** are less than zero, then the following condition needs to be satisfied $DC2<DC1<DC_{main}$ so that ions are sufficiently energized to be pulled through the ion guide. A minimum potential can form in the ion guide near the back end of the resistive insert where DC magnitude from resistive insert is at the lowest. The distance between the back end of the resistive insert and the second lens, and also the DC offset on the second lens, should be low enough to prevent potential well formation.

Referring back to FIG. **7**, gap **120** may include a first gap distance G**1** that represents a distance between two electrode portions at periphery **126** of the internal volume. In an embodiment, the first gap distance G**1** may range from about 0.5 millimeters to about 1.5 millimeters. As the first gap distance G**1** decreases, the distortion in the RF field decreases as well as the axial field strength effectively applied by the resistive insert. However, as the first gap distance G**1** increases, the distortion in the RF field increases, and the resistive insert can more effectively transmit a stronger axial field through the gap. Thus, a balance must be determined based on the uniformity of the RF field and the ability of the resistive insert to transmit a sufficiently strong axial field.

Under certain circumstances where there is a need for a simple design, an electrode may have uniform thickness where thickness is a distance between an outward surface and inward surface. However, in FIG. **7**, the thickness of the electrode is variable across the width W of the electrode. As illustrated in FIG. **7**, the electrode can include a first thickness T**1**, and second thickness T**2** at a protrusion portion **152** which illustrates a decreasing thickness at an area close to the gap. In an embodiment, width W may range from 0.4 centimeters to about 1.0 centimeters. Each electrode portion can include a protrusion portion **152** having an angle Θ at a point **154**. The angle Θ may range from about 10 degrees to about 50 degrees. The two respective electrode portions can be arranged so that the two points **154** form first gap distance G**1**. The two respective electrode portions can also be configured to have a larger second gap distance G**2** at the outward surface **150**. The electrode protrusion includes a smaller second thickness T**2** with a progressively decreasing thickness moving towards point **154**. A purpose of having the pointed electrode protrusion geometry is to create an effectively thinner electrode thickness proximate to the innermost surface **140** of the insert so that the axial field can be efficiently transmitted through the gap. In addition, this geometry also includes a larger first thickness T**1** away from the gap that improves the structural integrity and alignment of the electrodes for robust manufacturing.

FIG. **8** illustrates another embodiment of an ion guide **900**, which is similar to ion guide **100**, except that the electrodes (**902**, **904**, **906**, and **908**) extend outwardly to screen resistive inserts (**110**, **112**, **114**, and **116**) from fringing RF fields. Resistive inserts (**110**, **112**, **114**, and **116**) may be disposed within a cavity **952**. As an example, dotted arrow FR illustrates how the outwardly extending shape of electrode **902***b* can screen a fringing RF from electrode **906***a*. The purpose of the electrode design geometry is to reduce the possibility or exclude dissipative losses at the resistive insert through exposure to RF gradient fields.

Under certain circumstances, adjacent devices such as, for example, ion lenses or other quadrupoles can introduce fringing RF fields to a front or back end of an ion guide. To reduce such an effect, a front and back plate may be used for each of the electrodes to screen fringing RF fields. FIG. **11** illustrates a simplified partial perspective view of another embodiment of an ion guide **1200**. Ion guide **1200** is similar to ion guide **100**, except that each of the electrodes include a front plate and a back plate. The front plate can be located adjacent or attached to a front end of the electrode and the back plate can be located adjacent or attached to the back end of the electrode. As an example, FIG. **11** illustrates electrode **1202***a* and **1202***b* with a front plate **1230** attached to the front end. Resistive insert **110** may be disposed proximate to a longitudinally extending gap. Front plate and the back plate are configured to screen fringing RF field at the front and back ends of the ion guide. If plates are located adjacent, it is preferred that the same or close RF voltage is applied to these plates as the one on the electrodes **1202***a* and **1202***b*. In an embodiment, the front and back plates may be made of the same material as the electrodes.

FIG. **9** illustrates a front end view of another embodiment of an ion guide **1000**, which is similar to ion guide **100**, except that each electrode portion is in the form of an elongated rod **1002***a*, **1002***b*, **1004***a*, **1004***b*, **1006***a*, **1006***b*, **1008***a*, and **1008***b*. The elongated rods are arranged so that each pair of respective electrode portions form one electrode. Within a particular electrode, a first portion can be referred to with the suffix "a" and the other respective corresponding second portion can be referred to with the suffix "b." There is a longitudinally extending gap **1020** that is disposed in between two respective electrode portions. The plurality of electrodes (**1002**, **1004**, **1006**, and **1008**) can be arranged about a device centerline **118** in an octupolar like configuration to form an internal volume **1022**. The resistive inserts (**110**, **112**, **114**, and **116**) may be proximate to the longitudinally extending gap **1020**. The electrodes can include an inward tangential surface **1024** facing the device centerline **118** to form a periphery **1026** of the internal volume. The periphery **1026** is denoted as a dotted line in FIG. **9**. The resistive inserts (**110**, **112**, **114**, and **116**) can include an innermost surface **140** that faces device centerline **118**. The innermost surface **140** may be a first distance D**1** from periphery **1026** of the internal volume. In an embodiment, first distance D**1** can be approximately uniform for the entire length of the resistive insert.

Note that the configuration of ion guide **1000** will have a more open RF gradient field compared to ion guides **100** and **900**. For example, RF field gradient between electrodes **1002***b* and **1006***a* will propagate further into the location of resistive insert **110** because the open geometry of electrode **1002***b* does not completely shield resistive insert **110**. However, ion guide **1000** can still be a viable device so long as the resistive insert has as a sufficiently low dissipation loss factor.

FIG. **13** illustrates another embodiment of an ion guide **1300**. Ion guide **1300** is similar to ion guide **100** except that the electrodes and resistive inserts have been integrated into a printed circuit board **1332** (PCB). Such an embodiment can provide for a simple to construct and robust configuration because the electrodes and resistive inserts are integrated into a common PCB backbone. For simplification in illustration, only one electrode (**1302***a* and **1302***b*) and one resistive insert **1310** is illustrated as an end view of a portion of the ion guide. In constructing an actual ion guide **1300**, four electrodes and four resistive inserts can be used and assembled in a manner similar to ion guide **100**.

Referring to back to FIG. **13**, PCB **1332** includes an electrode **1302** and a resistive insert **1310**. Electrode **1302** is segmented into two electrode portions **1302***a* and **1302***b* to form a longitudinally extending gap **1320**. Ion guide **1300** also includes an isolator region **1334** that forms a discontinuity between the electrode portion and the resistive insert. Resistive inserts **1310** is proximate to the longitudinally extending gap **1320**. The electrodes can include an inward surface facing the device centerline to form a periphery **1326** of the internal volume. The periphery **1326** is denoted as a dotted line. The resistive inserts can include an innermost surface **1340** that faces device centerline. The innermost surface **1340** may be a first distance D**1** from periphery **1326** of the internal volume. In an embodiment, first distance D**1** can be approximately uniform for the entire length of the resistive insert.

Now that various ion guides with resistive inserts have been described, the following will describe an ion guide **1100** constructed in accordance with a different embodiment of the invention that includes conductive inserts. In general, ion guide **1100** is similar to ion guide **100** in regards to the electrode shape, structure, and orientation. In contrast to ion guide **100**, ion guide **1100** includes inserts that are more conductive than resistive inserts and have a tilted arrangement, as illustrated in FIGS. **10**A and **10**B. In an embodiment, the conductive inserts include a resistivity range typical of metals such as stainless steel that ranges from about 0.2×10^{-5} Ohm cm to about 1×10^{-5} Ohm cm.

FIGS. **10**A and **10**B illustrate, respectively, a front end view and a back end view of ion guide **1100**. Each of the four electrodes (**102**, **104**, **106**, and **108**) include a longitudinally extending gap **120** that splits the electrode into two separate portions displaced from one another. Within a particular electrode, a first portion can be referred to with the suffix "a" and the other respective corresponding second portion can be referred to with the suffix "b." The longitudinal gap **120** can extend the entire length of the electrode splitting it into separate portions. It should be noted that although ion guide **1100** is depicted as having four longitudinally extending gaps **120**, an alternative embodiment may include only two gaps so long as they are in an opposing format with respect to a device centerline **118**.

Referring back to FIGS. **10**A and **10**B, the plurality of electrodes (**102**, **104**, **106**, and **108**) can be arranged about a device centerline **118** to form an internal volume **122**. The internal volume includes a front end **136** configured to allow ions to enter and a back end **138** configured to allow ions to exit. The electrodes include an inward surface **124** that faces the device centerline to form a periphery **126** of the internal volume **122**.

A plurality of conductive inserts (**1156**, **1158**, **1160**, and **1162**) can be configured to be proximate to the longitudinally extending gaps **120**, as illustrated in FIGS. **10**A and **10**B. It should be noted that although ion guide **1100** is depicted as having four conductive inserts that are proximate to four longitudinally extending gaps, an alternative embodiment may include only two conductive inserts that are proximate to two respective gaps so long as they are in an opposing format with respect to the device centerline.

As illustrated in FIGS. **10**A and **10**B, the conductive inserts (**1156**, **1158**, **1160**, and **1162**) can include an innermost surface **1140** that faces device centerline **118**. FIG. **10**A illustrates a second distance D**2** that represents a distance between innermost surface **1140** and periphery **126** at front end **136**. FIG. **10**B illustrates a third distance D**3** that represents a distance between innermost surface **1140** and periphery **126** at back end **138**. Because the conductive inserts are configured in a tilted arrangement, the second distance D**2** is greater than third distance D**3**.

The innermost surface **1140** is an approximately flat portion of the conductive insert that is closest to and facing the device centerline **118**. In an embodiment, the innermost surface of the conductive insert may represent the portion closest to the periphery of the internal volume. The innermost surface does not have to be flat and may be a different shape such as, for example, a curved surface from a cylinder and a hyperbolic surface. In an embodiment, the conductive insert may be elongated rods where the rods can be cylinders, squares, rectangles, or other shape suitable for generating an axial field gradient that can guide ions.

In an embodiment, second distance D**2** may range from about 1 millimeter to about 2 millimeters and third distance D**3** may be about 0.5 millimeters for a conductive insert having a length of about 10 centimeters. The orientation slope of the conductive insert may range from about 0.005 milliradians to about 0.015 milliradians. Conductive insert may be made of material similar to those used for the electrodes and with a similar resistivity range. It should be noted that conductive insert may also be referred to as a metal insert.

Similar to ion guide **100**, the RF voltage supply can be configured to apply a RF voltage to the plurality of electrodes (**102**, **104**, **106**, and **108**) in ion guide **1100**. The application of the RF voltage will establish a RF field to radially confine ions along device centerline **118**. In an embodiment, a RF voltage having a first RF potential RF(+) can be applied to electrodes **102***a*, **102***b*, **104***a*, and **104***b*, and a RF voltage having a second RF potential RF(−) can be applied to electrodes **106***a*, **106***b*, **108***a*, and **108***b*, as shown in FIGS. **10**A and **10**B.

In an embodiment, the RF voltage supply **128** can also be configured to apply a RF voltage to the plurality of electrodes (**102**, **104**, **106**, and **108**) and the plurality of conductive inserts (**1156**, **1158**, **1160**, and **1162**). A RF voltage having a first RF potential RF(+) can be applied to electrodes **102***a*, **102***b*, **104***a* and **104***b*, and conductive inserts **1156** and **1158**. In addition, a RF voltage having a second RF potential RF(−) can be applied to electrodes **106***a*, **106***b*, **108***a*, and **108***b*, and conductive inserts **1160** and **1162**. It should be noted that the conductive inserts in ion guide **1100** are placed in an approximately zero gradient RF region. By placing the inserts in an approximately zero gradient RF region, there is little change in observed capacitance and RF frequencies in the ion guide with and without the application of an axial electric field gradient.

DC voltage supply **130** can be configured to apply a static voltage to the plurality of conductive inserts (**1156**, **1158**, **1160**, and **1162**). The application of the DC voltage can establish an axial electric field gradient along at least a portion of the device centerline. The static voltage may be referred to as a third DC voltage DC**3**. Where the second distance D**2** is greater than third distance D**3**, the third DC voltage DC**3** may range from about −50 to about −5 volts. For the situation where the third DC voltage DC**3** is a negative value, a "push" mechanism occurs to move ions along the ion guide.

DC voltage supply **130** may be electrically connected to the plurality of conductive inserts via wires. In an embodiment, a hole may be drilled into the conductive insert and a conductive epoxy, conductive adhesive, or solder may be used to secure the wire to the conductive insert. In another embodiment, a clip can be used to secure the wire into a hole in the conductive insert.

It should be noted that the configuration of ion guide **1100** with conductive inserts does not significantly change tank circuit parameters such as capacitance and RF frequency. Thus, only a relatively small amount of fine tuning is required for a smooth transition between implementing embodiment designs with and without a drag field.

In an embodiment, a method of guiding ions in a mass spectrometer includes injecting ions into an ion guide. A RF voltage can be applied to a plurality of electrodes to establish a RF field to radially confine ions. The RF voltage can also be applied to the plurality of inserts so that they are in an approximately net zero RF field. At least one DC voltage can be applied to the plurality of inserts to establish an axial electric field gradient along at least a portion of the device centerline. The axial field gradient moves the ions along device centerline so that the ions can be ejected. Next, the ejected ions can be measured as a detection current at a detector so that the detection current achieves a steady-state value ranging from about 0.3 to about 1 milliseconds or less.

In an alternative embodiment, an ion guide having conductive inserts may be configured to use a "pull" mechanism for moving ions along. Such an ion guide will have the conductive inserts tapered in an opposite manner than that of ion guide **1100** such that the second distance D**2** is less than third distance D**3**. Thus, in the alternative embodiment where the second distance D**2** is less than third distance D**3**, the third DC voltage DC**3** may be a positive value ranging from about +5 to about +50 volts.

While preferred embodiments of the present invention have been shown and described herein, it will be apparent to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. While the invention has been described in terms of particular variations and illustrative figures, those of ordinary skill in the art will recognize that the invention is not limited to the variations or figures described. In addition, where methods and steps described above indicate certain events occurring in certain order, those of ordinary skill in the art will recognize that the ordering of certain steps may be modified and that such modifications are in accordance with the variations of the invention. Additionally, certain of the steps may be performed concurrently in a parallel process when possible, as well as performed sequentially as described above. Therefore, to the extent there are variations of the invention, which are within the spirit of the disclosure or equivalent to the inventions found in the claims, it is the intent that this patent will cover those variations as well.

What is claimed is:

1. An ion guide comprising:

(a) a plurality of electrodes arranged about a device centerline to form an internal volume, at least two of the electrodes including a longitudinally extending gap, in which the longitudinally extending gap splits the electrode into two portions displaced from one another, the electrodes including an inward surface facing the device centerline to form a periphery of the internal volume;

(b) a plurality of resistive inserts, each configured to be proximate to a gap, and radially aligned with respect to the device centerline, the resistive inserts including an innermost surface that faces the device centerline where the innermost surface is a first distance from the periphery of the internal volume;

(c) a RF voltage supply configured to apply a RF voltage to the plurality of electrodes that establishes a RF field to radially confine ions, wherein the RF voltage supply is also configured to apply the RF voltage to the plurality of resistive inserts; and

(d) a DC voltage supply configured to apply a first DC voltage to a first location of the resistive insert and a second DC voltage to a second location of the resistive insert that establishes an axial electric field gradient along at least a portion of the device centerline, in which the second DC voltage is different than the first DC voltage and the second location is longitudinally spaced apart from the first location.

2. The ion guide of claim **1**, in which two of the resistive inserts are arranged in an opposing format with respect to the device centerline.

3. The ion guide of claim **1**, in which two the resistive inserts are arranged so that an approximately straight line intersects the two resistive inserts and the device centerline and goes through the gaps proximate to the two respective inserts.

4. The ion guide of claim **1**, in which the first distance is about the same at both the first and second locations of the resistive insert.

5. The ion guide of claim **1**, in which the resistive inserts and the electrodes include a first length and a second length, respectively, that extend approximately parallel with the device centerline and configured so that the first length and the second length are about the same.

6. The ion guide of claim **1**, in which the resistive inserts and the electrodes include a first length and a second length, respectively, that extend approximately parallel with the device centerline and configured so that the first length is less than the second length.

7. The ion guide of claim **1**, in which the device centerline is approximately straight, and the plurality of electrodes and the plurality of resistive inserts both include a longitudinal axis that is approximately parallel to the device centerline.

8. The ion guide of claim **1**, in which the device centerline includes a curvature, and the plurality of electrodes and the plurality of resistive inserts both include a curved longitudinal axis that corresponds to the curvature of the device centerline.

9. The ion guide of claim **1**, in which the plurality of electrodes are symmetrically arranged about the device centerline.

10. The ion guide of claim **1**, in which the plurality of resistive inserts are symmetrically arranged about the device centerline.

11. The ion guide of claim **1**, in which the difference in the applied voltage from the first location to the second location along the device centerline ranges from about 5 V to about 50 V.

12. The ion guide of claim **1**, in which the electrodes include an inward surface facing the device centerline having a shape selected from the group consisting of a curved surface from a cylinder, a flat surface, and a hyperbolic surface.

13. The ion guide of claim **1** further comprising a conduit configured to add a collision gas to the internal volume.

14. The ion guide of claim **1**, in which the first distance ranges from about 0.5 millimeters to about 1.0 millimeters.

15. The ion guide of claim **1**, in which the resistive insert has a resistivity ranging from about 106 to about 1010 ohms per square.

16. The ion guide of claim **1**, in which the gap ranges from about 0.5 millimeters to about 1.5 millimeters.

17. The ion guide of claim **1**, in which the resistive insert has a resistivity with a relative variation of less than about 10%.

18. The ion guide of claim **1**, in which the resistive insert has a dissipation loss factor greater than about 0.01 at 1 MHz.

19. The ion guide of claim **1**, in which the resistive inserts are proximate to and at least partially disposed within the gap.

20. The ion guide of claim **1**, in which the resistive inserts comprise a plastic.

21. A mass spectrometer comprising:

(a) an ionization source configured to ionize molecules;

(b) an ion guide configured to receive the ionized molecules, the ion guide comprising;

(i) a plurality of electrodes arranged about a device centerline to form an internal volume, at least two of the electrodes including a longitudinally extending gap, in which the longitudinally extending gap splits the electrode into two portions displaced from one another, the electrodes including an inward surface facing the device centerline to form a periphery of the internal volume;

(ii) a plurality of resistive inserts, each configured to be proximate to a gap, and radially aligned with respect to the device centerline, the resistive inserts including an innermost surface that faces the device centerline where the innermost surface is a first distance from the periphery of the internal volume;

(iii) a RF voltage supply configured to apply a RF voltage to the plurality of electrodes that establishes a RF field to radially confine ions, wherein the RF voltage supply is also configured to apply the RF voltage to the plurality of resistive inserts; and

(iv) a DC voltage supply configured to apply a first DC voltage to a first location of the resistive insert and a second DC voltage to a second location of the resistive insert that establishes an axial electric field gradient along at least a portion of the device centerline, in which the second DC voltage is different than the first DC voltage and the second location is longitudinally spaced apart from the first location.

(c) a mass analyzer configured to receive the ionized molecules from the ion guide and filter the ionized molecules so that a subset of ionized molecules having a particular mass to charge ratio passes through; and

(d) a detector configured to receive and measure the ionized molecules from the mass analyzer.

22. An ion guide comprising:

(a) a plurality of electrodes arranged about a device centerline to form an internal volume, the internal volume including a front end configured to allow ions to enter and a back end configured to allow ions to exit, where at least two of the electrodes including a longitudinally extending gap, in which the longitudinally extending gap splits the electrode into two portions displaced from one another, the electrodes including an inward surface facing the device centerline to form a periphery of the internal volume;

(b) a plurality of conductive inserts each configured to be proximate to a gap, the conductive inserts including an innermost surface that faces the device centerline where the innermost surface includes

(i) a first distance from the periphery of the internal volume at the front end, and

(ii) a second distance from the periphery of the internal volume at the back end, the first distance being greater than the second distance;

(c) a RF voltage supply configured to apply a RF voltage to the plurality of electrodes that establishes a RF field to radially confine ions, wherein the RF voltage supply is also configured to apply the RF voltage to the plurality of conductive inserts; and

(d) a DC voltage supply configured to apply a DC voltage to the conductive inserts that establishes an axial electric field gradient to move ions along the device centerline.

23. A method of guiding ions in a mass spectrometer, the method comprising:

(a) injecting ions into an ion guide, the ion guide comprising:

(i) a plurality of electrodes arranged about a device centerline to form an internal volume, the internal volume including a front end configured to allow ions to enter and a back end configured to allow ions to exit, where at least two of the electrodes including a longitudinally extending gap, in which the longitudinally extending gap splits the electrode into two portions displaced from one another;

(ii) a plurality of inserts, each configured to be proximate to a gap, the inserts including an innermost surface that faces the device centerline where the innermost surface includes a first distance from the device centerline;

(b) applying a RF voltage to the plurality of electrodes that establishes a RF field to radially confine ions;

(c) applying the RF voltage to the plurality of inserts; and

(d) applying at least one DC voltage to the plurality of inserts that establishes an axial electric field gradient along at least a portion of the device centerline.

24. The method of claim **23** further comprising:

(e) measuring a detection current at a detector configured to receive ions from the ion guide so that the detection current achieves a steady-state value within 1 milliseconds or less.

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